GEOLOGICAL AND GEOTECHNICAL INVESTIGATION OF EUREKA BEND, SH60, TAKAKA HILL, NEW ZEALAND

A Thesis

Submitted in partial fulfilment of the requirements of the degree

of

Bachelor of Science with Honours in Engineering Geology

at the

University of Canterbury

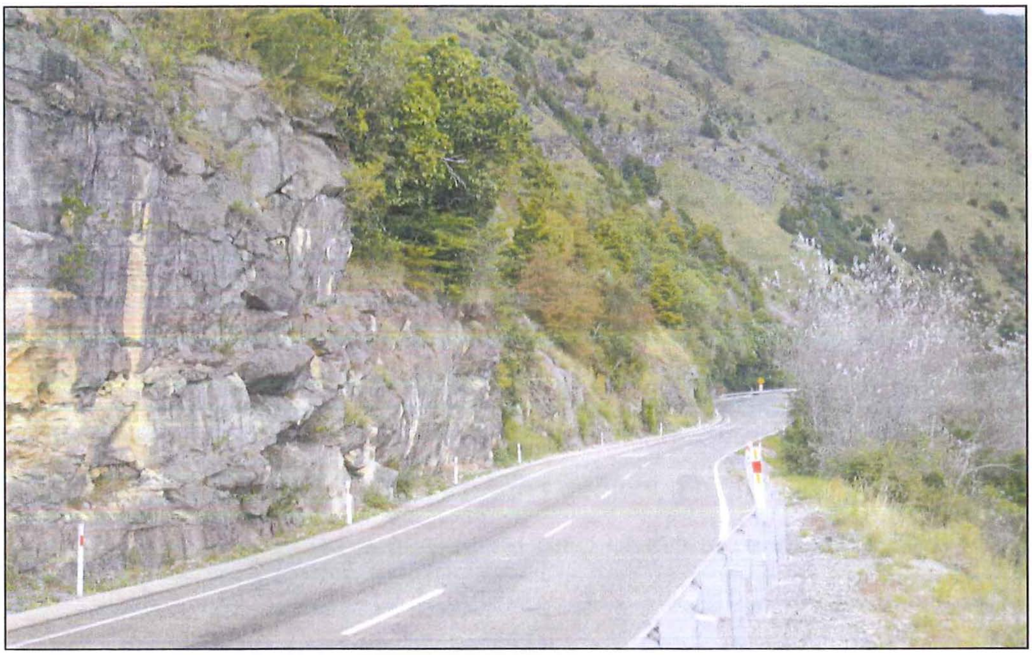
by

Timothy Michael Rutherford

UNIVERSITY OF CANTERBURY

2008

FRONTISPIECE



Looking south down SH60 towards Eureka Bend

ABSTRACT

The section of State Highway 60 that negotiates the western side of Takaka Hill has been subject to various instability issues over its lifespan, including colluvium landslides, planar failures in bedrock and fill collapses. As it is the only road into and out of Golden Bay it is imperative that it remains open as a means of access for residents and tourists alike.

Eureka Bend is a tight switchback corner on State Highway 60 near the bottom of Takaka Hill. It has been subjected to various types of historic instability and a recent failure within the road base that closed the road to one lane has required consideration of remediation options. GHD New Zealand have proposed to remove the weak fill and replace it with a reinforced earth embankment. They have also proposed to widen the turning radius of Eureka Bend to 15 m so that heavy vehicles may negotiate the corner without crossing the centreline. This would involve cutting into a 'block' of limestone that dips in a different direction compared to nearby limestone outcrops, and it is a detailed investigation into the local geology of the site and geotechnical assessment of the 'block' that is the subject of this project.

Field investigations involved collection of scanline data and rock samples for laboratory analysis, and general engineering geology observations of the study area. This data were analysed and a geological map of the area was created, along with kinematic analysis of the current cut face stability, rockfall analysis, and rock mechanics assessment involving point load and slake durability testing. Coupled with a literature review of previous work done in the area, conclusions were able to be made regarding the setting of the limestone 'block' and the design considerations that must be taken into account before any widening of the corner can commence.

From the analysis of the data collected, it is concluded that the limestone 'block' is not in-situ based on field observations that show its bedding clearly dips in a significantly different direction to limestone that is clearly in-situ to the north. The analysis of the current face shows that it is stable in its current setting, and various design scenarios have been analysed using the surface data available. The rock mechanics testing suggested that both the limestone and the marble are strong enough and durable enough for use as fill, and also to stand in the proposed cut face to realistic heights in the absence of penetrative daylighting defects.

ACKNOWLEDGEMENTS

Firstly, I would like to thank David Bell for his initial suggestion to study Eureka Bend and his ongoing guidance throughout the duration of the project. As my supervisor your knowledge and expertise in relation to my project has been invaluable.

I would also like to thank Peter Forrest of GHD New Zealand for agreeing to be my co supervisor and allowing me to partake in GHD's subsurface investigations on site. Your help throughout this project has ensured that I remained on track. Thanks must also go to Anna Mills of GHD for her help in the field and back here in Christchurch.

Many thanks to David Nobes for trekking up to Takaka with me to undertake an eventful GPR survey and also for proof reading my initial drafts.

Thank you to Cathy Higgins and Vanessa Tappenden for your help with the lab aspect of my project. Thank you for preparing samples and helping me with my testing. Without you it would have been a much more stressful experience. Thank you John Southward for your help with the computers and Anekant and Kate for help with Coreldraw.

Thank you Craig and Jenny Burnett for giving me a place to stay in Nelson while I was doing the field investigations. Also, thank you Craig for helping with the GPR survey. Thanks Shannon for putting up with me and helping out whenever you could. It was a big help.

I would also like to thank my flatmates, Greg, Jeremy and Nick. Thanks boys for keeping me sane this year.

Well done to the rest of the honours crew, Rob, Jimmy, Islay and Rebecca.

Finally I would like to thank Mum and Dad. Without your support it would have been a much tougher year.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1

Introduction: Eureka Bend

1.1 Project Background

State Highway 60 between Tasman Bay and Golden Bay in northwest Nelson is the only road that provides access for residents and tourists to this part of the country. For this reason the road is vitally important as it acts not only as a means of access but also as a lifeline for the people of Golden Bay. The road itself traverses Takaka Hill, rising from virtually sea level on the eastern side up to 791 m above sea level at its highest point before descending steeply into the Takaka Valley.

Due to the local geology and the steep terrain that the road has been built on, it has suffered ongoing stability issues since its initial construction. These instability issues not only include failures within the natural subsurface, such as bedrock failures and colluvium slumps, but also can be related to the fill that the road has been built on. When the initial single lane road was widened to two lanes in the early 1950s, fill consisting of various materials including schist, limestone, marble and river gravels, was side cast off the edge of the existing road. The fill was never compacted properly and correct drainage measures were not installed which effectively caused the subsequent failures that have continued to occur beneath the road.

Recently one of these failures beneath the road at Eureka Bend has reduced the road to one lane and requires the use of a Bailey bridge to span the affected section of road. This has prompted Transit New Zealand to employ the services of GHD Limited. They have been requested to conduct the relevant investigations that allow them to make recommendations to address the ongoing stability issues of the section of road in question. The present research project has been designed to assist GHD by determining the geological and geotechnical issues that relate to a small section of the Eureka Bend site.

1.2 Location of Field Area

Eureka Bend is located on State Highway 60 at RP 56/10.9 on the western side of Takaka Hill in Golden Bay, northwest Nelson. It is approximately 21 km south of

Takaka and 70 km northwest of Nelson, as shown in Figure 1-1. The study area focuses on a section of the highway near the small township of Upper Takaka, where the road switches back on itself at a corner known as Eureka Bend. The topography of the site is generally very steep, with slopes upwards of 35° in places. Elevations in the wider site range from 200 m to 600 m above sea level, and currently the primary land use is for farming purposes.

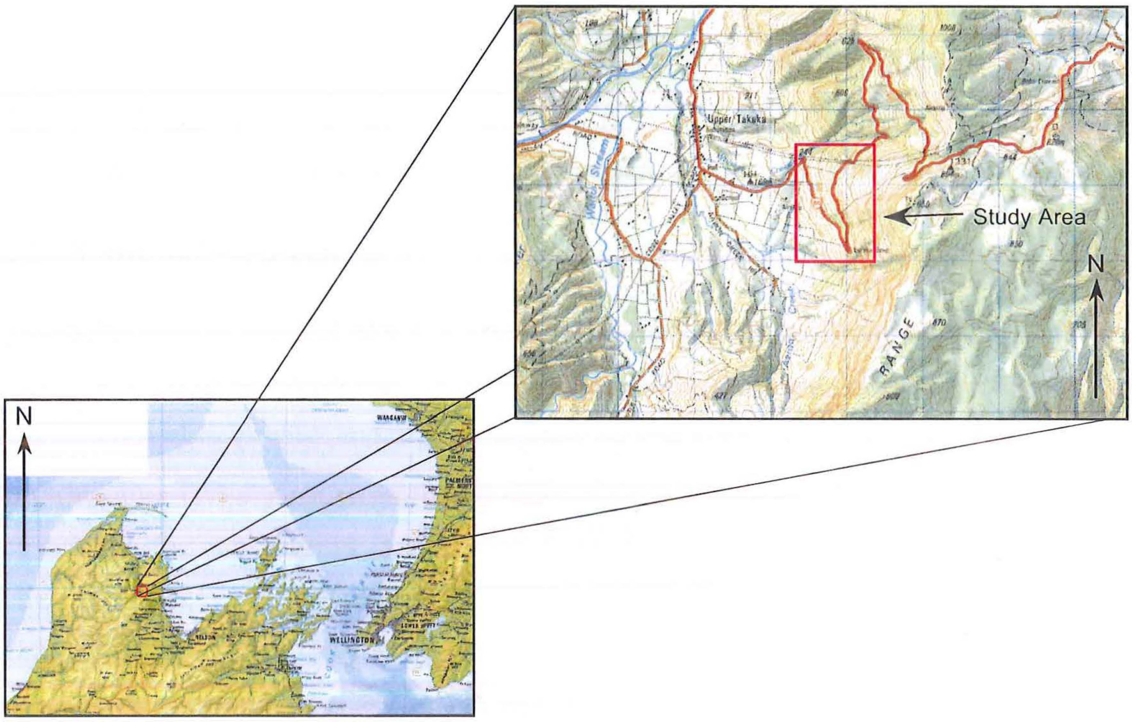


Figure 1-1: Location of Eureka Bend field area, Takaka, New Zealand. (TOPOMAP Map Toaster, MapWorld New Zealand. 1997-2004)

1.3 Project Aims and Objectives

This project aims to carry out a series of geological and geotechnical investigations to assist with the possible reconstruction of Eureka Bend on Takaka Hill. These include:

- Engineering geology mapping and face logging of the limestone "block" on the uphill side of Eureka Bend.
- Engineering geophysical surveys of the uphill side of this "block" to determine rock continuity and probable colluvium depth.
- Compilation of drill hole and test pit data into an engineering geology model for the uphill and downhill segments of Eureka Bend.
- Rock mechanics investigations to determine limestone strength parameters and the properties of apparent bedding plane defects.

- Computer modelling of stability and evaluation of any implications for the reconstruction of the rock face by drilling and blasting.

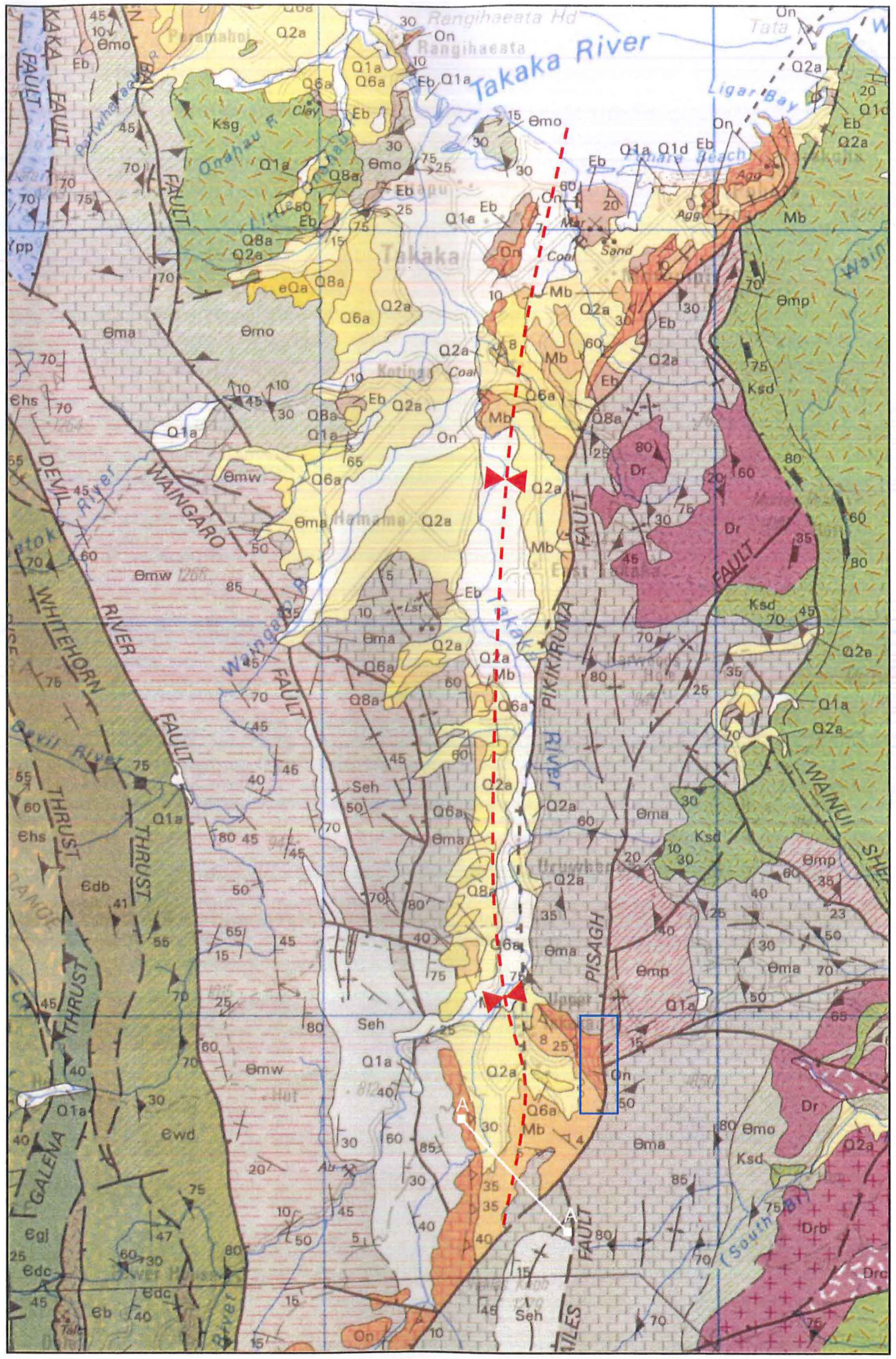
The primary objective of this research has been to carry out a detailed assessment of the rock face and "block" to assess its likely performance in widening of the cut at Eureka Bend. A secondary objective is to further assess overall rock mass behaviour in the limestone, and the suitability of excavated materials for use as engineered fill.

The overall aim of this project is to assist in improving the safety and reliability of State Highway 60 over Takaka Hill for both residents and tourists alike.

1.4 Regional Geology

The study area is located at the southern end of the Takaka Valley which is a north-south trending depression filled with Tertiary and Quaternary sediments (Figure 1-2). The eastern side of the valley is controlled by the Pikikiruna and Pisagh Faults that separate the Tertiary rocks from the older Paleozoic rocks. On the western side of the valley the sediments are either faulted or lie uncomformably against the Paleozoic rocks. The Paleozoic rocks of the study area were faulted and folded during both the Tuhua and Rangitata orogenies. During the Tuhua orogeny (370 to 330 million years ago) the Pikikiruna schist and the overlying Arthur Marble formed a broad open anticlinal structure in the vicinity of the study area, while further south the schist was tightly refolded (Grindley, 1980). The Rangitata orogeny (140 to 100 million years ago) saw the development of major strike-slip movement along faults such as the Pikikiruna and Pisagh faults (Grindley, 1980).

From the Eocene to Miocene the area underwent a marine transgression followed by a regression over a peneplaned surface of Paleozoic rocks (Jongens, 1992). The Kaikoura orogeny, which continues today, saw uplift and reverse faulting of the basement rocks begin. Compressional forces during this time folded the rocks of the Takaka Valley into a north-south trending syncline with a steep eastern limb and a shallower western limb, as shown by Figure 1-2b (Jongens, 1992). All underlying basement rocks were then covered with Quaternary river alluvium from glaciation in the catchment of the Takaka River and tributaries (Grindley, 1980; Rattenbury *et al.*, 1998).



QUARTERNARY

Unit	Description
Q1a	Well sorted gravel forming modern flood plains and young fan gravels (Q1a)
Q2a	Clay-bound gravel and minor fan deposits forming lowest aggradation surfaces above major rivers (Q2a).
Q2a	Clay-bound poorly sorted gravel forming alluvial fans and colluvial deposits (Q2a).
Q6a	Slightly weathered gravel and minor fan deposits forming intermediate aggradation terraces (Q6a)

TERTIARY

LOWER BLUE BOTTOM GROUP Calcareous mudstone and muddy sandstone (Mb).
NILE GROUP Bioclastic limestone and muddy limestone (On).

Mb
On

SULURIAN

ORDOVICIAN

Seh
Omo
Oma
Omw
Omp

HAILES QUARTZITE and FOWLER FORMATION Quartzite, quartz sandstone, and siliceous siltstone (Seh).
ONEKAKA SCHIST Siliceous biotite-muscovite schist and quartzite bands (Θmw).
ARTHUR MARBLE 2 Limestone and calcareous mudstone, with sparse corals and crinoids (Θma).
WANGAPEKA and BALDY FORMATIONS Siliceous siltstone, calcareous siltstone, and quartz sandstone, with limestone beds (Θmw).
PIKIKIRUNA SCHIST Quartz-biotite-muscovite-garnet schist with quartzite bands (Θmp).

Key
- Syncline
- Study Area
- Faults
A A' - Cross section line

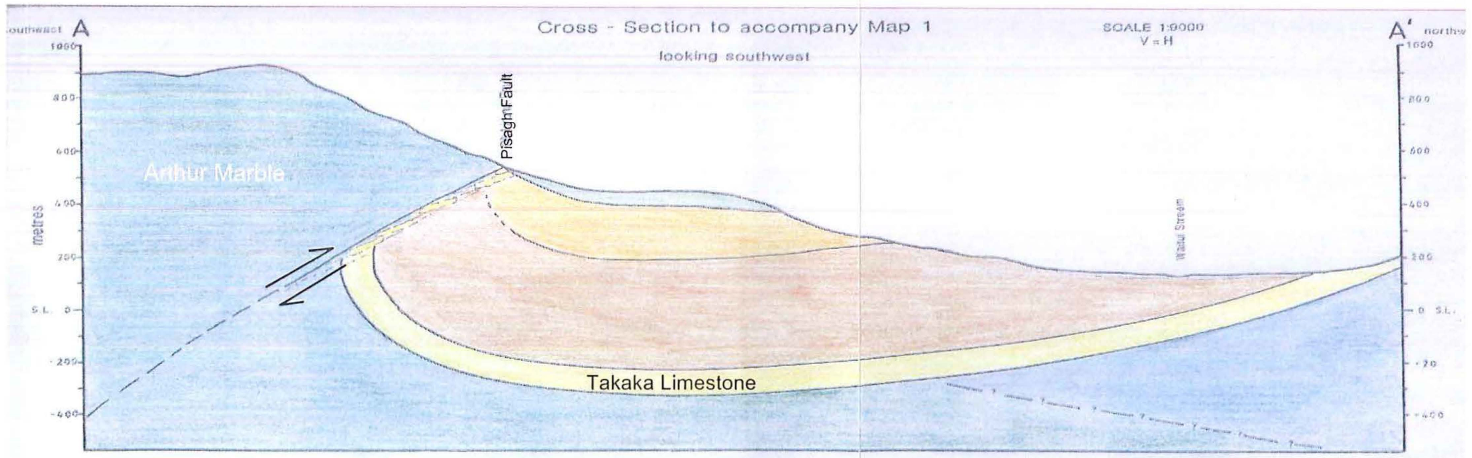


Figure 1-2: Geological map and cross-section showing the regional geological setting of the Takaka Valley and the study area. (Adapted from Jongens, 1992 and Rattenbury *et al.*, 1998)

1.5 History of Instability

The western side of Takaka Hill has had various instability issues related to the topography and the geology of the area ever since the road was first constructed. Whenever a failure occurs it will usually have the effect of closing down one or even both of the lanes. Generally the failure can be cleaned up relatively quickly and traffic flow resumed, however some of the failures have required remediation measures that have reduced the width of the highway sometimes for over a year.

1.5.1 Failure Terminology

1.5.1.1 Slide Failures

Cruden and Varnes (1996) describe slides as a downward and outward movement of a soil or rock mass along a surface of rupture that can be either translational or rotational in nature. Rotational slides fail along a surface of rupture that is curved and concave usually within homogenous materials such as soils and fills, as shown in Figure 1-3a. In translational slides the mass moves along a planar or undulating surface of rupture (see Figure 1-3a). This surface is typically the result of a bedding plane or a joint set within a rock mass, oriented in the right way to facilitate sliding. If the surface of rupture is formed by two intersecting discontinuities and the mass fails down the line of the intersection, a wedge slide will occur (Cruden & Varnes, 1996).

1.5.1.2 Falls

A rock or earth fall involves the detachment of rock or soil from a steep slope along a weak surface such as a joint or fracture plane. The material then descends mainly through the air by falling, bouncing, or rolling, as shown in Figure 1-3a (Cruden & Varnes, 1996). This material may also be susceptible to secondary falls, which involve rock that has already detached from the face and is simply lodged on it.

1.5.2 Types of Instability on Takaka Hill

The primary slide failures that can be observed along the Eureka Bend section of SH60 are planar failures within the limestone, and these are generally controlled by bedding that dips steeply towards the road, as shown by Figure 1-3d. Jointing within the limestone also results in small secondary wedge failures, together with the initial planar failure. Rotational failures within the roading fill have also occurred, usually as a result of poor construction practices, such as the current failure that is restricting traffic to one lane below Eureka Bend (see Figure 1-3e). Remediation measures used include scaling, rock bolting, and wire mesh to reduce the planar failure hazard to the road. Failures within the fill have historically been topped up with extra fill and resealed. Currently there is a Bailey bridge acting as a temporary remedial measure to allow traffic to negotiate the most recent failure within the fill.

A combination of the steep topography and the highly fractured nature of the Arthur Marble high upslope create a potential rock fall hazard to the road (see Figure 1-3c). The semi-spherical shape of the marble blocks means that they will easily begin to roll and the steep terrain allows them to gather a lot of momentum before reaching the road. Occasionally large boulders will cause significant impact damage to the road surface that requires repairs.

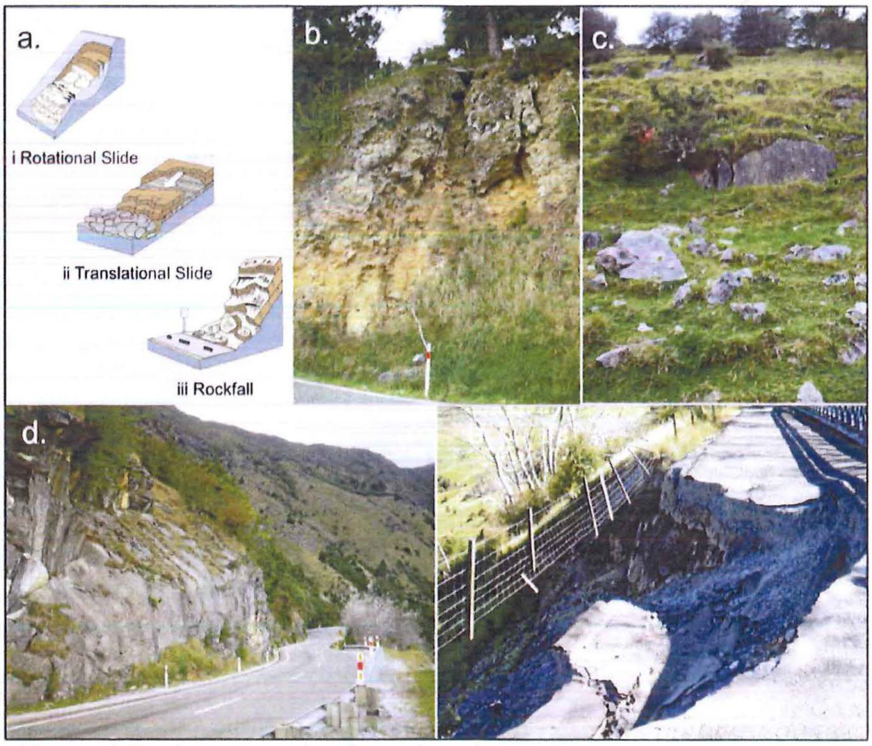


Figure 1-3: Examples of various slope failures adjacent to Eureka Bend. a. Failure methods, b. Slump within colluvium, c. Rockfall boulders, d. Planar failure in limestone, e. Rotational failure in fill. (a. is adapted from <http://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html>).

Earth falls and slumps within the road batter are also present (Figure 1-3b). They are primarily related to reworked marble breccia that appears to have been sourced from further upslope. The cutting for the road has exposed the slumps to the elements, which has seen an acceleration in weathering thus reducing the strength of the matrix. Subsequently material has fallen from the near vertical face onto the road surface below.

1.5.3 Previous Failures

Table 1-1 shows the recent failure history within the vicinity of Eureka Bend.

Table 1-1: Recent failure history of the study area.
(Adapted from GHD, 2007 and MWH, 2006)

Date	Location	Type of Landslide	Remedial Measures
1960s	200m north of Eureka Bend, downslope of lower carriageway	Planar failure in limestone	Temporary Bailey Bridge installed Crib wall constructed
1990	500m north of Eureka Bend, upper carriageway	Dropout from road shoulder	None
1990	400m north of Eureka Bend, upper carriageway	Tension cracks and slight depression in outside lane	None
1992	200m north of Eureka Bend, downslope of lower carriageway	Planar failure in limestone	Tied-back railway iron/timber retaining wall
1994	~250m north of Eureka Bend, downslope of upper carriageway	Planar failure in limestone	Removal of loose blocks and debris
1998	~220m north of Eureka Bend, downslope of upper carriageway	Failed block wall and fill	13m long anchored gabion wall on piled foundations. Underpinned in 2000/2001
1999	~180m north of Eureka Bend, downslope of upper carriageway	Planar failure	Scaling, rock bolting and wire mesh in 2000/2001
2002	200m north of Eureka Bend, downslope of lower carriageway	Block fall/slide	Removal of loose blocks and steel mesh
2003	~80m north of Eureka Bend, downslope of upper carriageway. Directly above location of current Bailey Bridge	Slump within fill, tension cracks	Topped up and resealed
2004	~30m north of Eureka Bend, along lower carriageway	Slump, tension cracks 65 m in length across whole road	Topped up and resealed
2006	~30m north of Eureka Bend, at 2004 failure location	Slump within fill removed road edge. Tension cracks	Temporary Bailey Bridge constructed – still in place

1.6 Project Format and Methodology

The geological and geomorphological setting of the study area is presented in Chapter 2 as the basis for a more localised study of the area immediately adjacent to Eureka Bend. Chapter 3 then focuses on the remediation options proposed by GHD, and a more detailed assessment of the limestone 'block' in the current road cutting for Eureka Bend including field investigations and emplacement theories.

In Chapter 4 all the rock mechanics and stability testing is presented and discussed. This assessment of rock mechanics data fulfils the aim of assessing whether the material excavated at Eureka Bend is suitable as fill, and if it is strong enough to stand in a near vertical cut face.

Chapter 5 then outlines and discusses the design considerations that need to be assessed for the proposed widening of Eureka Bend. Finally, Chapter 6 provides a summary of project conclusions and recommendations.

Chapter 2

Site Engineering Geology

2.1 *Introduction*

This section focuses on the localised geology and geomorphology of the study area as well as compiling subsurface investigations done by MWH and GHD. From this information an engineering geology model of the site was created.

Three weeks were spent in the field conducting a detailed geological assessment of the study area shown in Figure 1-1. Exposure of the outcrops was relatively poor throughout the site with the best outcrops exposed as a result of the State Highway 60 road cutting that traverses much of the study area. A detailed geological map (Map 1), cross-sections and geological descriptions have been compiled from a review of previous work done in this area coupled with the recent fieldwork. A regional geology map and stratigraphic column is included as Figure 1-2.

2.2 *Bedrock Geology*

2.2.1 Pikikiruna Schist

The Pikikiruna schist outcrops towards the northeast of the study area, primarily outcropping along the road cutting, however there are some limited outcrops exposed in small gullies further upslope. It has a faulted contact with the Arthur Marble to the south along an inferred normal fault, and another faulted contact with the Takaka Limestone to the west along the Pisagh Fault. A third faulted contact with the Arthur Marble at Pylon Point has to be inferred as there is not enough outcrop to establish accurately the nature of the contact (Figure 1-2).

Figure 2-1: Examples of the Pikikiruna Schist outcropping at Pylon Point.

The schist itself can be described as dark greenish grey, quartz-muscovite-biotite-garnet schist, interbedded with thin-bedded metaquartzite, marble and dolomite (Grindley, 1980). It is highly susceptible to weathering in exposed faces such as road cuttings, and is slightly to moderately weathered within the study area where iron staining gives it a pale yellow colouration (see Figure 2-1).

2.2.2 Arthur Marble

The Arthur Marble that is observed within the study area is termed Arthur Marble 2 by Cooper (1979), and is found towards the eastern side of the study area. It is in faulted contact with the Pikikiruna Schist to the north and has been thrust over the Takaka Limestone by the Pisagh Fault to the east (Figure 1-2).

The Arthur Marble within the study area is coarse grained, blue-grey to cream marble with minor interbedded schist and quartzite, as shown by Figure 2-2 (Grindley, 1980). It is probably Middle Ordovician in age (Grindley, 1980). Metamorphism is low and crinoid stem fragments can often be observed (Jongens, 1992). Within the study area the marble is highly fractured, forming semi-spherical blocks 0.1 m to >1 m in diameter. It is also shows fluting. There are also zones of brecciation within beds and fractures that range up to 1 m+ thick zones consisting of cemented tabulate clasts as shown by Figure 2-2b (Jongens, 1992).

Figure 2-2: Examples of Arthur Marble.
a. Fresh marble. b. Brecciated zone within marble beds.

2.2.3 Marble Breccia

A marble breccia derived from reverse faulting along the Pisagh Fault was observed along a linear trend from Eureka Bend through to Pylon Point. The source rock for the breccia is Arthur Marble 2 that would have been brecciated as it was thrust over the Takaka limestone. It can be described as a moderately weathered, dark grey breccia with angular clasts ranging in size from 5 mm to 600 mm bound together by flowstone, as shown by Figure 2-3 (GHD, 2007).

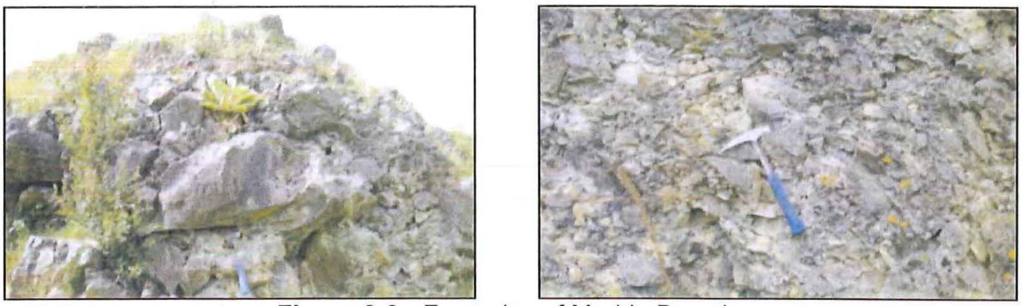


Figure 2-3: Examples of Marble Breccia.

2.2.4 Takaka Limestone

The Takaka Limestone lies in faulted contact along the Pisagh Fault with the Arthur Marble and the Pikikiruna Schist (Figure 1-2). However, the zone of marble breccia discussed in Section 2.2.3 means that the units do not actually come into physical contact.

The limestone can be described as well bedded, slightly weathered, pale yellowish grey limestone. Beds range in thickness from 300 mm to 500 mm locally (see Figure 2-4 c. & d.). Bryozoa dominate the limestone, with varying quantities of echinoid plates, bivalves, brachiopods, foraminifera and algae also present (see Figure 2-4a). The age of the limestone is late Oligocene to early Miocene (Grindley, 1980). The limestone was probably deposited in a shallow to middle shelf environment reflecting a period of tectonic rest (Leask, 1980).

Figure 2-4: Examples of Takaka Limestone.
a. Bivalves within the limestone. b. Blocky zone. c. & d. Well bedded limestone.

Just north of Eureka Bend a zone of highly fractured limestone can be observed. Figure 2-4b shows no real sign of structure, and bedding is generally not present within this zone ,suggesting that it may have been associated with faulting.

2.2.5 Faulting

The relationship of the different units to one another within the study area suggests that the area has been subjected to various different types of fault movement throughout its history. All three major types of faults (normal, reverse and strike slip) are present within the study area.

2.2.5.1 Pisagh Fault

The Pisagh Fault is the major fault within the study area. Grindley (1980) initially mapped it as the Pikikiruna fault, however Rattenbury *et al* (1998) have it mapped as the Pisagh fault and that term is used here. They map the location of the Pikikiruna fault parallel to, but slightly to the west of the Pisagh Fault (Figure 1-2).

The Pisagh fault itself strikes virtually north-south across the study area from Pylon Point to just above Eureka Bend, as shown by Map 1 and Figure 1-2. It is a reverse fault with uplift on the eastern side that thrusts the Ordovician Arthur Marble over the younger Oligocene Takaka Limestone. Grindley (1980) suggests that the fault was initially dextral strike-slip, as shown by the 4 km dextral offset of the Devil River Thrust south of the study area. It is not known when strike-slip movement occurred along the Pisgah Fault but it was possibly during the late Mesozoic (Jongens, 1992). Reverse faulting related to the Kaikoura Orogeny would have then begun during the late Miocene to develop the present structures (Jongens, 1992).

2.2.5.2 Other Faults

Grindley (1980) mapped a normal fault that separates the Pikikiruna Schist to the north from the Arthur Marble to the south. The fault trace is clearly visible in the field however there is very little evidence to indicate which way it is offset.

A third fault is possibly present towards the north of the study area, separating the Arthur Marble from the Takaka limestone at Pylon Point. This fault is entirely inferred as it does not appear in outcrop, therefore there is no evidence to indicate what movement has occurred. However, it must exist because there has to be a faulted contact between the Arthur Marble and the Takaka limestone as these two units are not conformable due to their significant age difference.

2.3 Surficial Geology

2.3.1 Colluvium

Suficial deposits of colluvium are observed along the road cutting north of Eureka Bend. It appears to be reworked and recalcified breccia that has been transported down slope as a landslide. It consists of clasts of marble and limestone held together by an orange-brown silty fine sand matrix (see Figure 2-5). Thicknesses of about 6m are observed in the road cutting north of Eureka Bend.

Much of the limestone outcrop below the Pisagh Fault and in the road cutting has been obscured due to the nature of the colluvium.

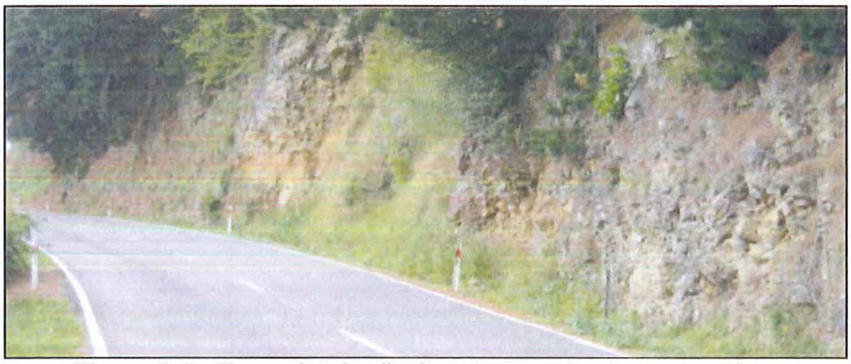


Figure 2-5: Example of colluvium outcropping in road cutting.

2.4 Geomorphology

Due to the geological make up and steep nature of the study area there are many geomorphological features present. These are shown on Figure 2-9 and are discussed below.

2.4.1 Deep-seated Failures

From studies of aerial photography and field investigations three deep-seated failures were indentified within the study area above Pylon Point. The head scarps of all three appear to be connected suggesting that they are located within unstable geology, as shown by Figure 2-6. The origins of the failures are within the brecciated material associated with the Pisagh fault, which may have been the triggering mechanism. They all appear to be rotational landslides in nature meaning that the failure plane must be within a homogenous medium such as the breccia and not bedrock that would see defect controlled failure surfaces (Cruden and Varnes, 1996).

All three landslides appear to have been subjected to erosional processes for a significant period of time and therefore are believed to significantly pre-date the construction of State Highway 60. The lack of recent movement or tension cracks suggest that the landslides are inactive and are therefore of only minor concern to the ongoing stability of the road.

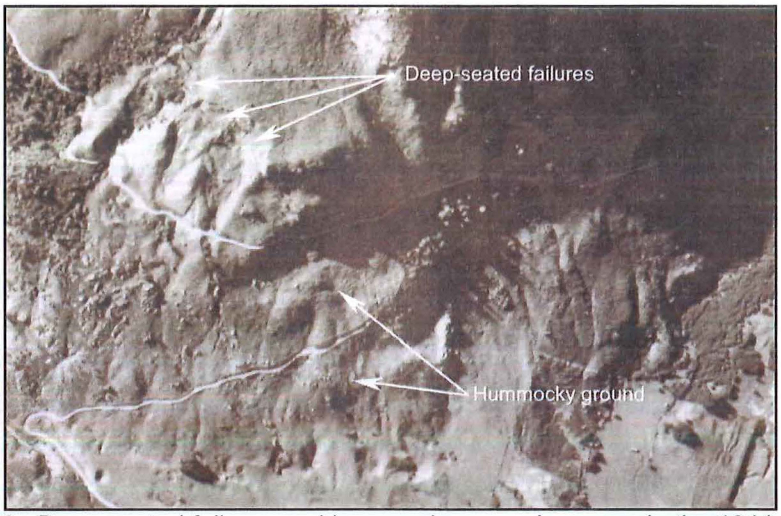


Figure 2-6: Deep-seated failures and hummocky ground as seen in the 1944 air photo.

2.4.2 Hummocky Ground

There is a zone of hummocky ground that extends downslope from the scarp created by the Pisagh fault to the bottom of the hill (see Figure 2-6). Hummocky ground suggests that the area has been subjected to slope instability in the past and the uneven ground is evidence of this. The most likely source of slope instability is within the marble breccia associated with the Pisagh fault. Reworked breccia (colluvium) along the upper carriageway road cutting north of Eureka Bend provides evidence that the breccia has been subjected to instability in the past, which may have caused large volumes of material to slide down slope thus creating the hummocky ground that is visible both above and below the road.

From field observations there is no evidence to suggest that a mass movement of the slope is likely to occur in the near future. However, the proximity of the proposed failure to the Pisagh fault indicates that the fault may have been the triggering mechanism and any reactivation along the fault may create further instability, which may affect the road.

2.4.3 Bedrock Planar Failures

Planar failures along bedding surfaces within the well-bedded limestone can be seen north of Eureka Bend both on the upper and lower carriageway (see Figure 2-7). Here the limestone bedding dips towards the road at around 40 – 50° meaning that it is inherently unstable. From aerial photography analysis it is possible to see that the failures had not occurred pre-1944 and even the 1989 photos do not show evidence of failures in this area. Therefore, the likely cause of the failures is related to the widening of the road in the 1950s, which would have removed support from the toe of the slope. The removal of vegetation from the affected slopes post 1989 also removed supporting roots that would have bound the blocks together.

Under the correct conditions such as increased pore water pressure due to heavy precipitation, or seismic shaking, there is a high possibility that further planar failures will occur along this section of the road.

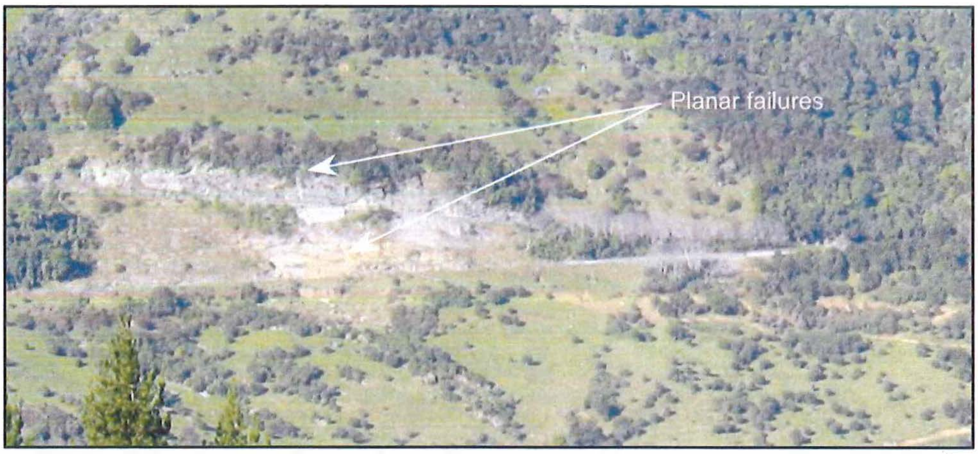


Figure 2-7: Planar failures above the upper and lower carriageways north of Eureka Bend.

2.4.4 Fill Slumps

Failures within the poorly compacted roading fill have been occurring beneath the road forcing the closure of one lane for a significant period of time. When the road was widened to two lanes in the 1950s fill was side cast over the edge of the road and substandard compaction practices were used to compact the fill. Consequently failures within the fill have begun to occur when water manages to penetrate into it.

2.4.5 Karst Terrain

Karst terrain is evident in the study area as sink holes both within the limestone at the base of the hill and the marble breccia above the road. Dissolution and collapse of the underlying limestone and marble when it comes in contact with water has created the undulating terrain that is seen at the base of the hill (see Figure 2-8).

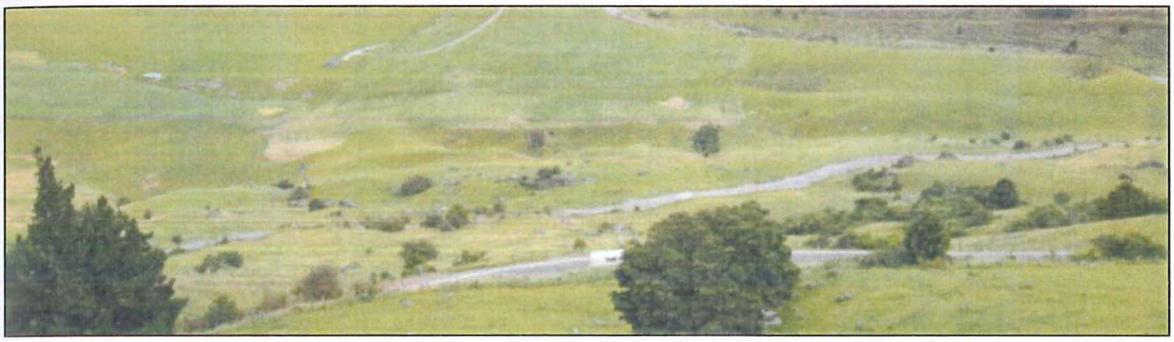


Figure 2-8: Sinkholes within karst terrain at the base of the hill.

2.4.6 Steep Terrain

The whole study area is located on very steep terrain that ranges from about 20° to over 40° in places. It is effectively the scarp slope of the Pikikiruna Range that was formed when the Pisagh fault thrust the Arthur Marble over the Takaka limestone.

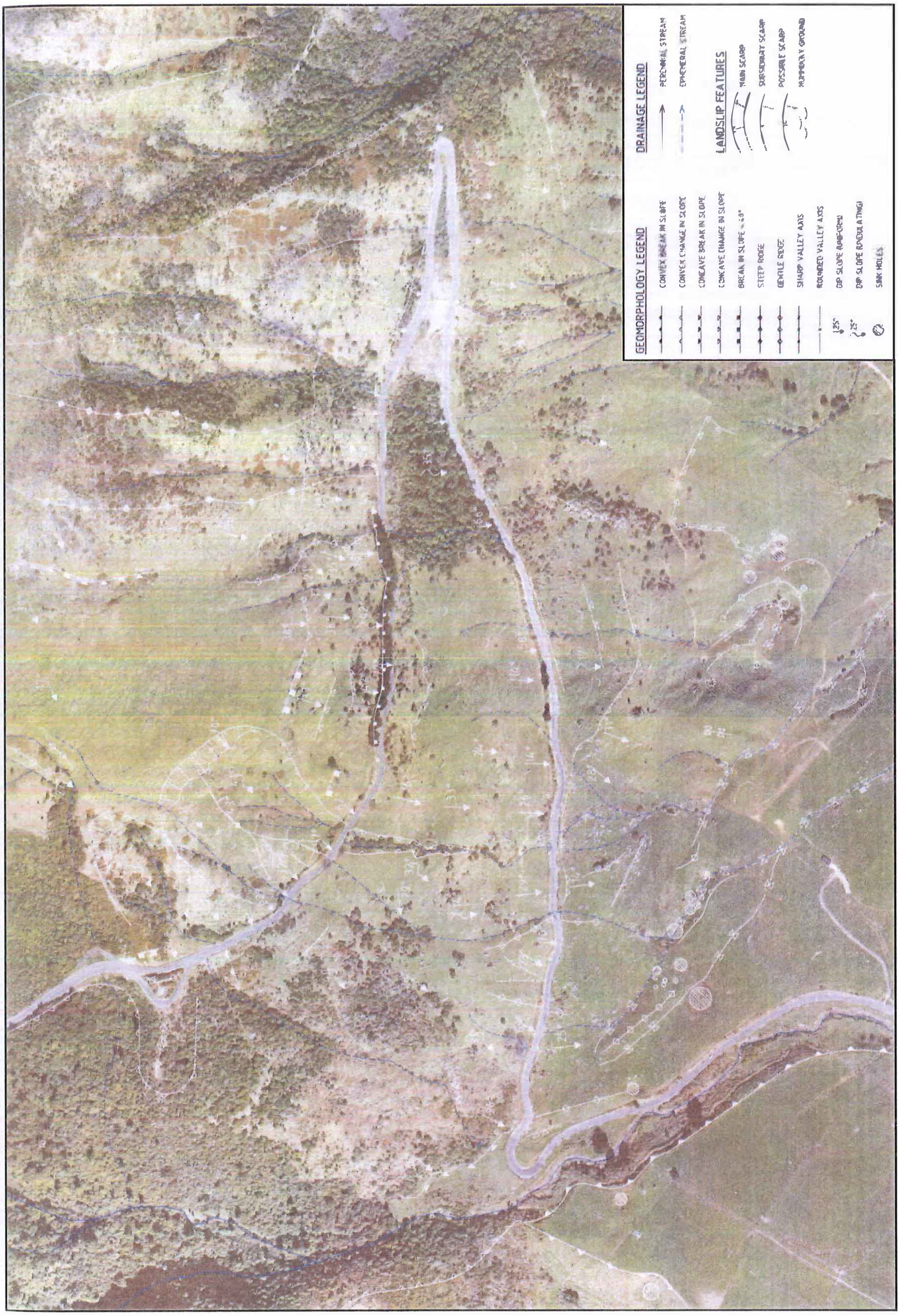


Figure 2-9: Geomorphological map of the study area.
(Source: GHD Ltd, 2007)

2.5 Site Investigations

Due to the various instability issues associated with the study area several companies have undertaken subsurface geological and geotechnical investigations on behalf of Transit New Zealand in an attempt to understand more about the problems. Both MWH Global Limited and GHD Limited have been involved with these investigations on separate occasions. Map 2 shows the locations of all the subsurface investigations that were done by both companies.

2.5.1 MWH Investigations

In mid-2006 MWH New Zealand Limited were asked by Transit New Zealand to undertake a geotechnical assessment of the landslip at RP 56/10.91 adjacent to Eureka Bend. The slip occurred sometime between the 14^{th} and 16^{th} of August 2006 (location shown in Map 2), affecting about 7 m of seal and requiring the lanes to be moved 2.5m towards the inside of the road (MWH, 2006). In addition to a desk study MWH also conducted a subsurface investigation in September 2006 that involved (locations of subsurface investigations are shown on Map 2):

- Three boreholes to a maximum depth of 17. 3m.
- Four test pits near the toe of the slip to a maximum depth of 4.1 m, six along the inside edge of the highway and one on the upper carriageway directly above the slip.

Their findings are summarised in the Table 2-1 and 2-2 below, and the original logs are included in Appendix 1.

Table 2-1: Summary table of MWH borehole data for Eureka Bend.

	Depth to base of (m):				
	Clayey Gravel – FILL	**Clayey Gravel**	**Gravelly Clay**	**Silty Clay**	**SW – MW Limestone**
Borehole #1	0.8	3.6	5.8	8.3	Terminated 17.3
Borehole #2	0.8	3.6	6.0	8.4	Terminated 14.3
Borehole #3	0.5	2.4	–	3.6	Terminated 14.4

Note: *SW = slightly weathered*
MW = moderately weathered

From Table 2-1 the contact between the overlying silty clay layer and the limestone bedrock has been identified at about 8.3 m – 8.4 m in borehole 1 and 2. Both these boreholes were located on the outside edge of the carriageway at similar elevations, while borehole 3 was located towards the inside of the road which accounts for the shallower depth to bedrock observed in that hole. In all three boreholes the water used as drilling flush was lost at the silty clay/bedrock contact, which suggests that the limestone contains voids (MWH, 2006). This was confirmed by further drilling that showed the presence of several voids within all three drill holes.

Table 2-2: Summary table of MWH test pit data for Eureka Bend.

	Depth to base of (m):				
	Asphalt	**Topsoil**	**Sandy Gravel – FILL**	**Silty Clay**	**Limestone**
Test Pit #1	–	0.3	–	4.0	Terminated 4.1m
Test Pit #2	–	0.2	–	2.8	Terminated 3.0m
Test Pit #3	–	0.1	–	1.5	Terminated 1.6m
Test Pit #4	–	0.1	–	3.1	Terminated 3.2m
Test Pit #5	0.1	–	1.1	4.0	Terminated 4.1m
Test Pit #6	–	–	0.4	–	Terminated 0.5m
Test Pit #7	–	–	0.8	1.7	Terminated 1.8m
Test Pit #8	–	–	0.4	1.1	Terminated 1.2m
Test Pit #9	–	–	0.4	2.5	Terminated 2.6m
Test Pit #10	–	–	0.4	2.4	Terminated 2.5m
Test Pit #11	–	0.3	1.8	Terminated 3.5m	–

Therefore the test pits conducted by MWH in September 2006 show the limestone – silty clay interface between 1.5 m and 4.0 m below the surface along the base of the slip and 1.1 m to 4.0 m along the inside shoulder of the road. However, no limestone was encountered in TP-11 located on the upper carriageway above the slip due to a greater thickness of fill.

2.5.2 GHD Investigations

GHD Limited was requested by Transit New Zealand to carry out additional geological and geotechnical investigations following the issue of their Identification of Options Report in September 2007, which examined remediation options for Eureka Bend. The scope of their subsurface investigation in September 2007 involved the completion of another borehole and two additional test pits. All three sites were located close to each other along the outside edge of the upper carriageway above the Bailey bridge and current failure (see Map 2 for detailed locations).

Table 2-3: Summary table of GHD initial borehole and test pit data for Eureka Bend.

	Depth to base of (m): Asphalt	Gravel & Gravelly Sand – FILL	Clay	Sandy Clay - FILL	Clayey Gravel	MW – CW Limestone	Fresh Limestone
Borehole #101	–	0.9	–	–	4.0	14.6	Terminated 24.0
Test Pit #101	0.1	0.6	–	Terminated 2.2m	–	–	–
Test Pit #102	0.1	0.8	2.5	Terminated 4.0m	–	–	–

***Note:** MW = moderately weathered and CW = completely weathered*

Table 2-3 shows contact with the limestone at 4.0 m, however this limestone is heavily weathered and contains many voids (see original borehole logs, Appendix 2). Fresh unweathered limestone is not encountered until 14.6 m and continues until the hole is terminated at 24 m. Both test pits TP-101 and TP-102 only act to expose the roading fill, and did not penetrate to the limestone.

Following this initial work, further subsurface investigations were conducted in March 2008 to provide information regarding the suitability of the subsurface adjacent to and below the current landslip for the foundations of a reinforced earth embankment as part of their remediation plan. Five test pits were conducted to a maximum depth of 5.2 m. All encountered limestone at a depth of between 1.5 m and 5.1 m. They are summarised in Table 2-4 below, and their original logs are included in Appendix 2.

Table 2-4: Summary table of GHD March 2008 test pit data for Eureka Bend.

	Depth to base of (m): Topsoil	FILL	Clayey Silt / Clay	Silty Clay	Limestone
Test Pit #201	0.1	–	0.9	3.2	Terminated 4.2m
Test Pit #202	0.1	2.1	5.1	–	Terminated 5.2m
Test Pit #203	0.1	2.8	3.3	–	Terminated 4.0m
Test Pit #204	0.1	0.8	2.6	–	Terminated 3.1m
Test Pit #205	0.2	–	1.5	–	Terminated 1.6m

2.6 Site Drainage

An investigation into the natural and man made surface drainage paths of the study area was undertaken by GHD Ltd in 2007. They created a plan showing all surface water courses as well as man made water tables and culverts (see Figure 2-10).

There is a poor understanding of the groundwater flow of the area but from the sinkholes and the voids that were logged during drilling it is safe to assume that the groundwater will flow within the cavities of the karst terrain.

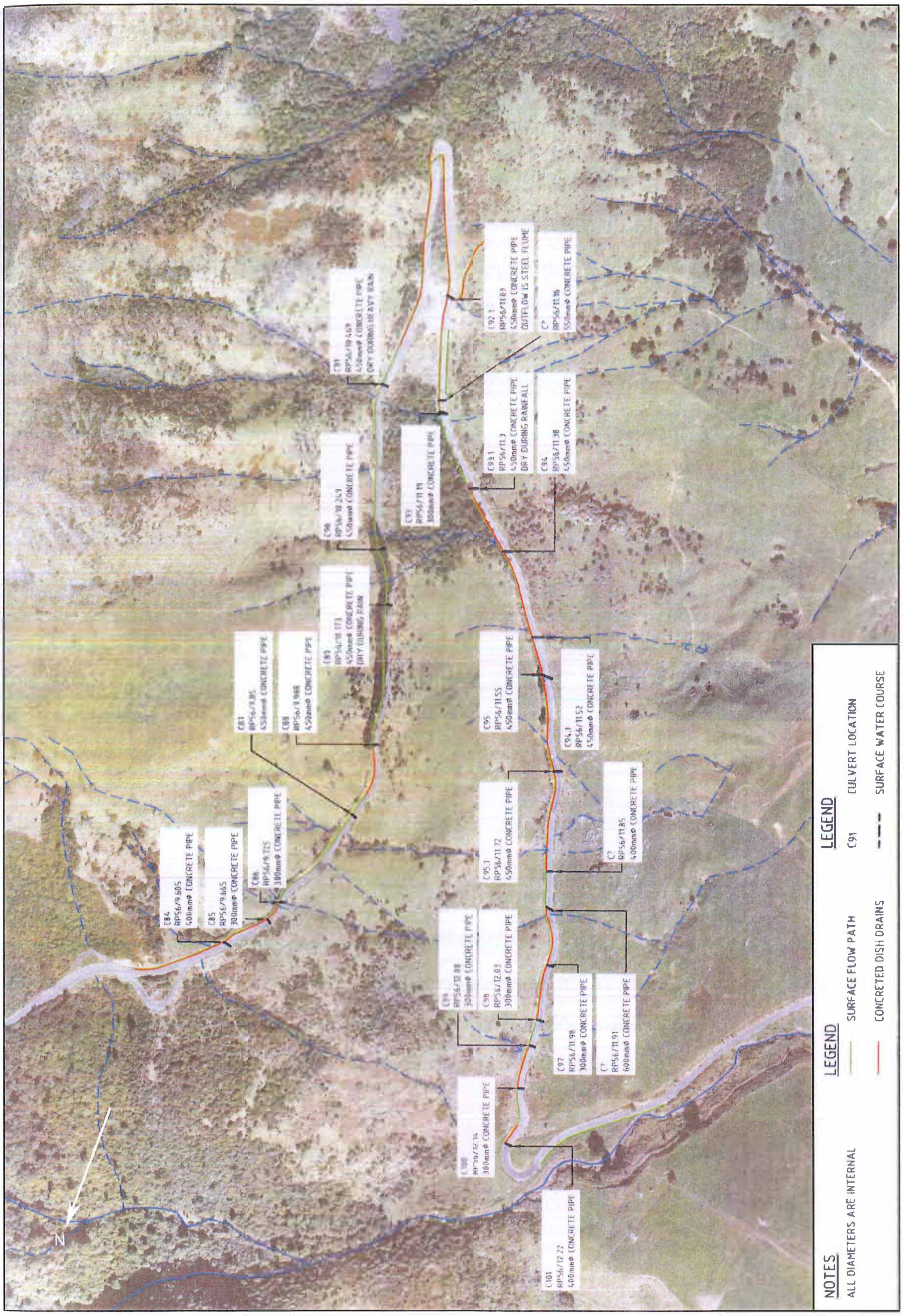


Figure 2-10: Surface drainage for study area.
(Source: GHD Ltd.)

2.7 Eureka Bend Engineering Geology Model

Using the information discussed in Sections 2.1 and 2.2 the following cross-section (Figure 2-11) was created to provide a better understanding of the subsurface beneath Eureka Bend (location is shown in Map 2). From Figure 2-11 it is possible to see the fill makes up the first layer beneath the road surface. This overlies a sandy/gravelly clay before limestone bedrock is met at a depth of between 3.6 m and 8.3 m. From GHD's investigations it was determined that the top surface of the limestone had been subjected to erosional processes and that fresh unweathered limestone was not encountered until 14.6 m.

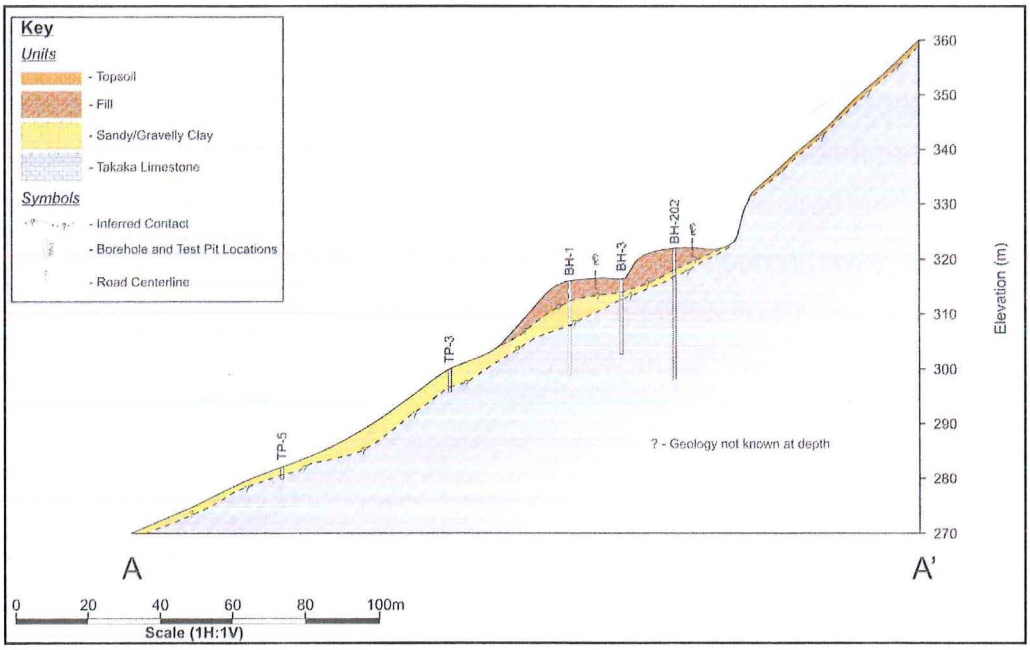


Figure 2-11: Cross-section A-A' through Eureka Bend.

2.8 Geotechnical Issues Associated with the Study Area

There are many geotechnical issues that need to be addressed within this study area if the security of the road is to be ensured for future generations. These are:

- Stability of the land above and below the road. This includes:
    - Failures within natural ground.
    - Failures within made ground.
    - Failures related to human intervention, i.e. road cuttings.
- Surface and groundwater drainage issues.
- Safety concerns for the road including rockfall hazards.
- Suitability of fill materials for use reinforced earth embankment.
- Rock batter design for proposed rock cut above Eureka Bend.

Chapter 3

Proposed Eureka Bend Cut Investigation

3.1 Remediation Options

After reviewing MWH's work and conducting their own investigations, GHD have come up with the following four proposed options for the remediation of the Eureka Bend and the stabilisation of the current slip beneath the lower carriageway.

1. Reinforced earth fill on current alignment

   This proposal involves the excavation of the poor fill material from beneath the lower carriageway before replacing it with a free draining reinforced earth embankment founded on competent bedrock. Additional drainage meausres will also be installed to ensure groundwater does not undermine the integrity of the earth embankment. Approximately 80 m of the lower carriageway will be affected by this proposal, but because of its staged construction process traffic access should not be disrupted too much. This option should provide security to both the upper and lower carriageways.

2. Restoration of Bailey Bridge with Geometric Improvement

   This option will incorporate the engineered earth embankment discussed in Option 1, but it will also include a geometric realignment of Eureka Bend which will allow heavy vehicles to negotiate the corner with less difficulty. The proposed alignment shown in Figure 3-1 will create a 15 m curve radius with 0.5 m wide sealed shoulders and 0.5 m wide drain that will allow a B-train to round the corner without crossing the centreline. As with Option 1 improved drainage will have to be installed to ensure that groundwater does not create problems both for the earth embankment and for the new cut profile. This option will see a cut of about 25 m into the limestone at Eureka Bend, which will have the added benefit of providing fill for the engineered earth embankment on the lower carriageway. Due to the large-scale excavation that is needed during the cutting stage, traffic flow may be interrupted for a short period of time.

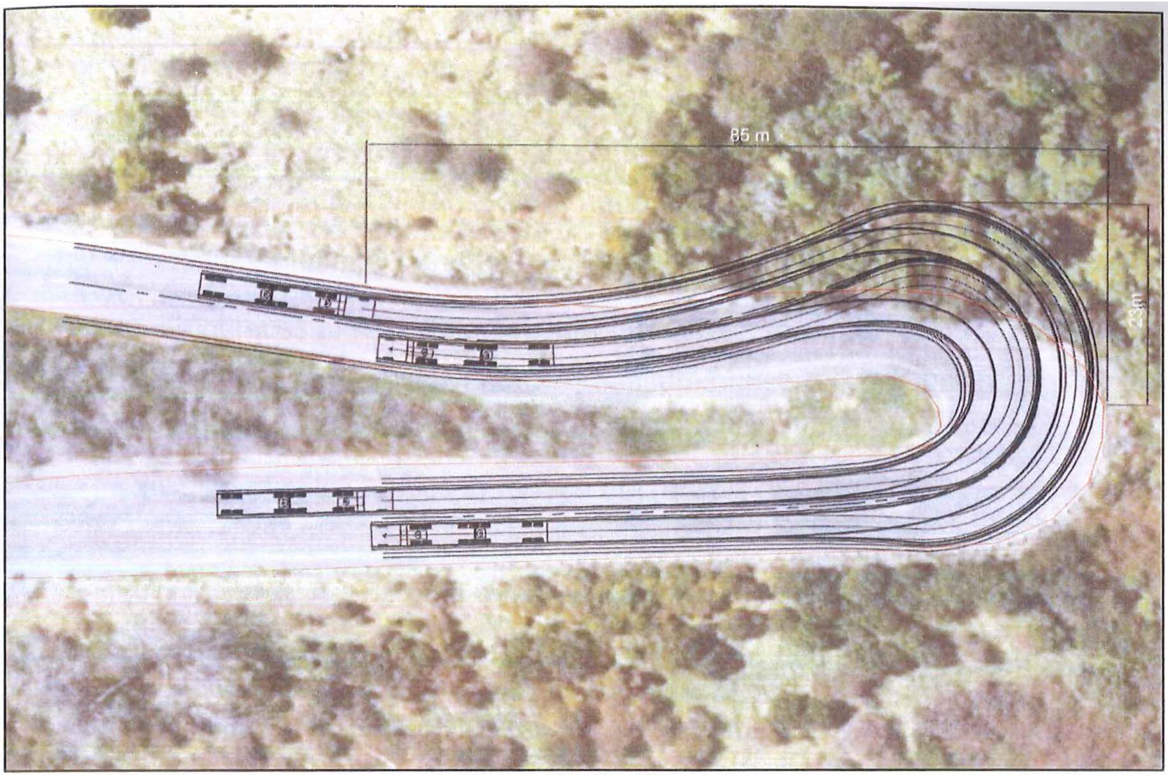


Figure 3-1: Option 2 proposed realignment of Eureka Bend showing B-train tracking curve. (Source: GHD, 2007)

3. <u>Stormwater Management</u>

   This option involves an upgrade of the current stormwater management measures to ensure that water is diverted into specific channels, and not allowed to penetrate the road fill where it may cause instability due to increased pore water pressures. Measures that are proposed include:

   - Slot drains to intercept runoff that poses a risk to embankment and slopes.
   - Reconstruction of current inside lane drainage channels from Pylon Point to beneath Eureka Bend, with concrete dish drains used to ensure that no water is able to penetrate into the fill.
   - Inlets and outlets of many culverts will need to be redesigned to minimise blockages and prevent discharge that may have a negative effect on the roads foundations.
   - Road cambers that promote surface runoff towards unprotected road verges, with drainage measures installed to divert runoff away from areas of fill.

4. Rock Slope Remediation

   Option 4 involves indentifying segments within the study area that are subject to slope instability that may ultimately affect the security of the road. Remediation of these 'at risk' zones would require the physical removal of rocks and soil that are having a detrimental effect on the stability of the zone. Measures include:

   - Scaling of faces to remove potentially dangerous rocks,
   - Slope re-profiling and preventative measures such as rock bolting and mesh to prevent rocks from reaching the roadway,
   - Installation of catch fences to reduce the rockfall risk,
   - Removal of vegetation that may be having a detrimental effect on slope stability.

This thesis has direct relevance to Option 1 and Option 2 that were proposed by GHD. As mentioned in Section 1.3 this project's primary objective is to carry out a detailed assessment of the rock face and "block" to assess its likely performance in widening of the cut at Eureka Bend as pertains to Option 2. A secondary objective is to further assess overall rock mass behaviour in the limestone, and the depth and properties of colluvium affecting reconstruction which is relevant to both Option 1 & 2.

3.2 Assessment of Limestone Block

3.2.1 Definition of Problem

When the geology of the study area is looked at in a broader context there are two issues that arise.

1. The dip of the limestone beds at Eureka Bend differs from the dip of the limestone further to the north both above the upper and lower carriageways. Figure 3-2 shows how bedding adjacent to Eureka Bed dips to the south at 25°, while bedding to the north generally dips in a west to southwest orientation at 30° - 50°.

2. The presence of Arthur Marble on top of the limestone 'block'. This marble is located nearly 100 metres downslope of the in-situ marble on the up thrown side of the Pisagh Fault.

The aim of this section is to determine whether the limestone adjacent to Eureka Bend is in-situ and therefore may be related to a fold structure, or whether it has been displaced and is in fact a large 'raft'.

Various investigations were carried out during the field component of my research to assist in the assessment of the limestone 'block' adjacent to Eureka Bend. These included:

- Thorough site walk over and inspection of relevant outcrops,
- Detailed geological mapping of the zone in question, and,
- A geophysical survey using ground penetrating radar (GPR) to determine continuity of the limestone and the relationship of the 'block' to limestone further to the north.

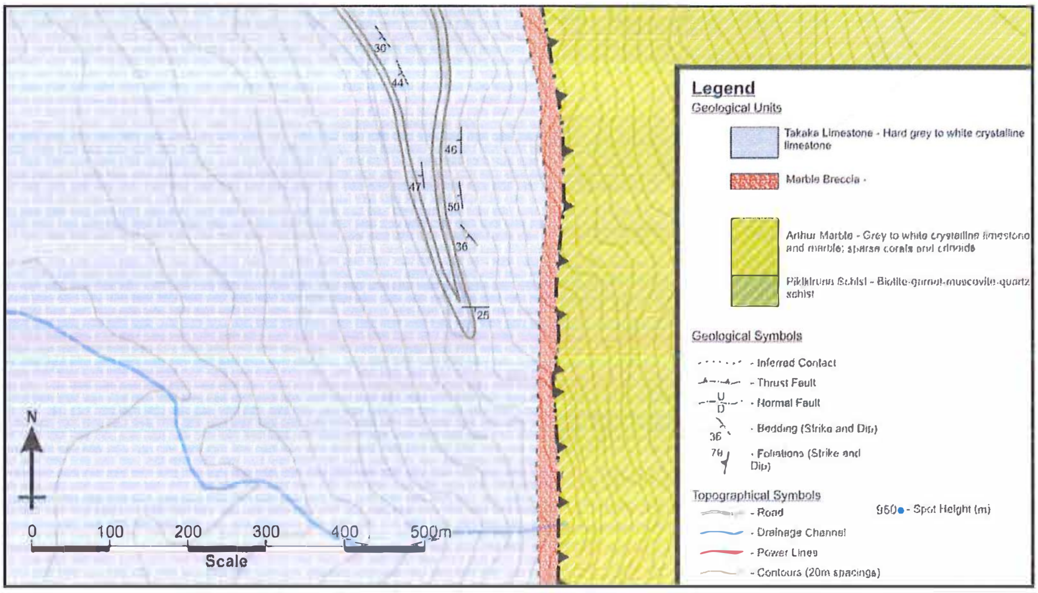


Figure 3-2: Bedding orientation adjacent to Eureka Bend.

3.2.2 Site Inspection

A thorough site inspection was conducted to determine the geology and structure of the area upslope of Eureka Bend. Arthur Marble was encountered above the road cutting at Eureka Bend in the form of two 'steps' both about 1.5 m – 2 m in height as shown in Figure 3-3a. Slickenslides were observed on parts of the 'step' and are shown in Figure 3-3b. Some possible jointing was observed within the marble, however, because of a high level of degradation due to weathering it was difficult to record their orientations. Spacings of these joints were about 2 m. Brecciated material was also observed along defect planes within the marble, and examples of this can be seen in Figure 2-2b. Larger homogeneous outcrops of brecciated marble can be seen immediately to the south of Eureka Bend. They are similar in composition to the breccia seen upslope, with angular clasts of marble held in a fine-grained calcareous matrix. It is unlikely that the breccia was formed in-situ, but it is possible that it is the result of a mass movement of Arthur Marble and fault breccia from further up slope.

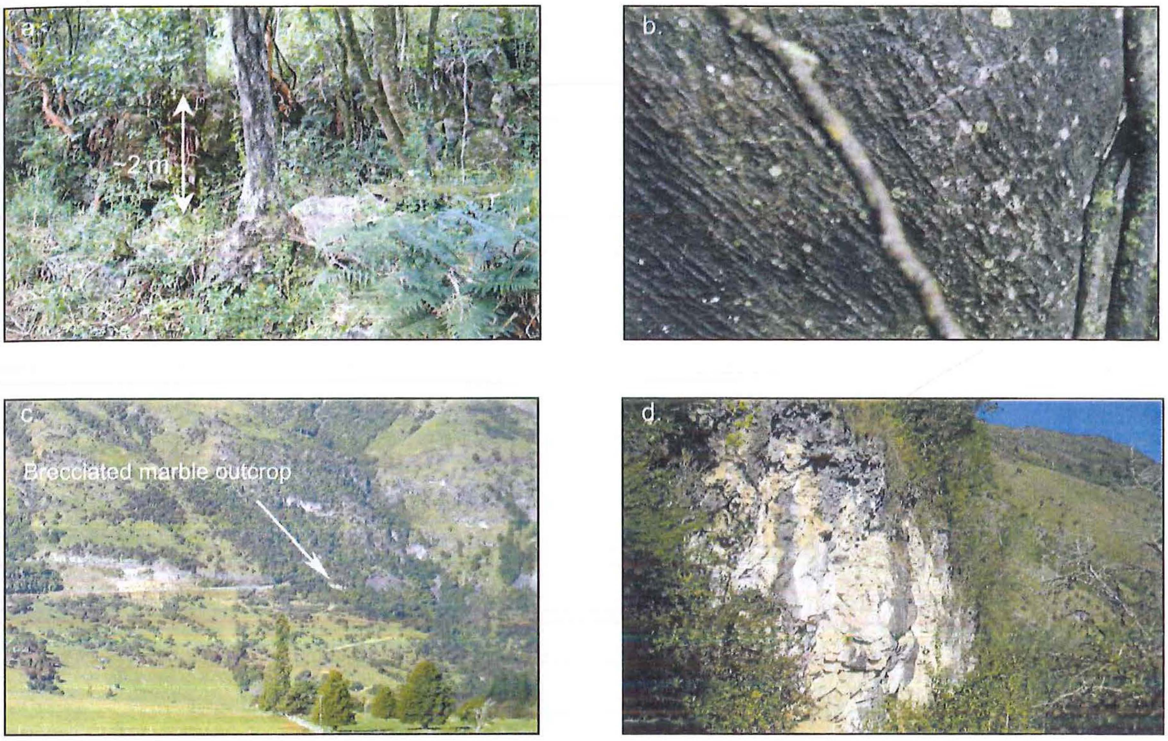


Figure 3-3: Marble step located upslope from Eureka Bend.
a. Step in the marble. b. Slickenslides on the marble. c. Location of breccia marble. d. Brecciated marble outcrop.

3.2.3 Detailed Geological Mapping

As part of the field mapping exercise that was completed earlier in the year, a detailed geological map was produced of the study area (Map 1). From this map it is possible to see how the geology relates to Eureka Bend itself. The road cutting for Eureka Bend is cut directly into Takaka limestone, which from Figure 3-2 can be seen to be dipping to the south at 25°. This is in direct contrast to the limestone that is observed north of the bend above both the upper and lower carriageway, which can be seen to be dipping in a west to southwest orientation at 30° - 50°.

The Pisagh fault is located further upslope above Eureka Bend, and Arthur Marble can be found overlying a marble breccia along the fault trace. No other faults appear to intersect or directly affect the specific area around Eureka Bend.

3.3 *Geophysical Investigations*

3.3.1 Methodology

Initially the geophysical survey was going to be done using seismic refraction in an attempt to determine the subsurface structure of the area in question. It was anticipated that it would be possible to identify jointing or faulting that may have resulted in the limestone having a different bedding orientation to elsewhere in the study area. Due to the very steep terrain and the thick vegetation directly above the road cutting, however, it was decided that the seismic survey would logistically be too difficult to run. The similar nature of the lithologies involved, both limestone and marble, may have also meant that interpretation of any data obtained would have been very difficult. Therefore, the decision to use ground penetrating radar (GPR) was made because it would be easier to use on site.

The fundamental principles of GPR are described by Davis and Annan (1989). 50 MHz antennas were chosen for this investigation, as they would provide deeper penetration of the subsurface while still providing a resolution that would enable interpretation of relatively small-scale structures beneath the ground (Jol and Bristow, 2003). The two 50 MHz antennas were mounted 2 m apart on a plywood sled (Figure 3-4), which was then pulled up the slope where readings were taken every 0.5 m. The GPR traverse is shown on Map 2, and this process was then repeated along the same line but in the opposite direction to confirm the reproducibility of the data.

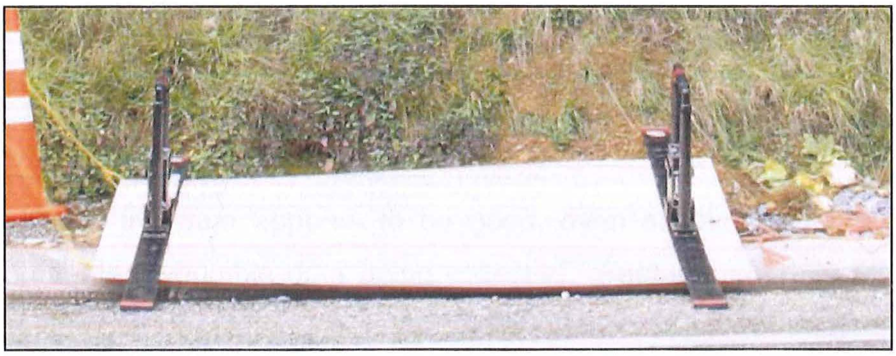


Figure 3-4: Equipment used during the GPR survey.

3.3.2 GPR Results

The results obtained during the two GPR traverses are shown in Figure 3-5. Due to an operator error during the collection of the results it was not possible to carry out any processing such as adding topography or migration to remove diffractions.

The top part of Figure 3-5 shows the data that was collected during the uphill traverse. From this data it is possible to see a series of joints that when corrected for a 35° - 40° slope will appear sub-horizontal. A subhorizontal layer is also seen within the data, and it is possible that this is a bedding plane within the limestone because again when the data is corrected for topography it will appear sub-parallel to the surface with a similar orientation to the bedding that is observed in the road cutting to the north.

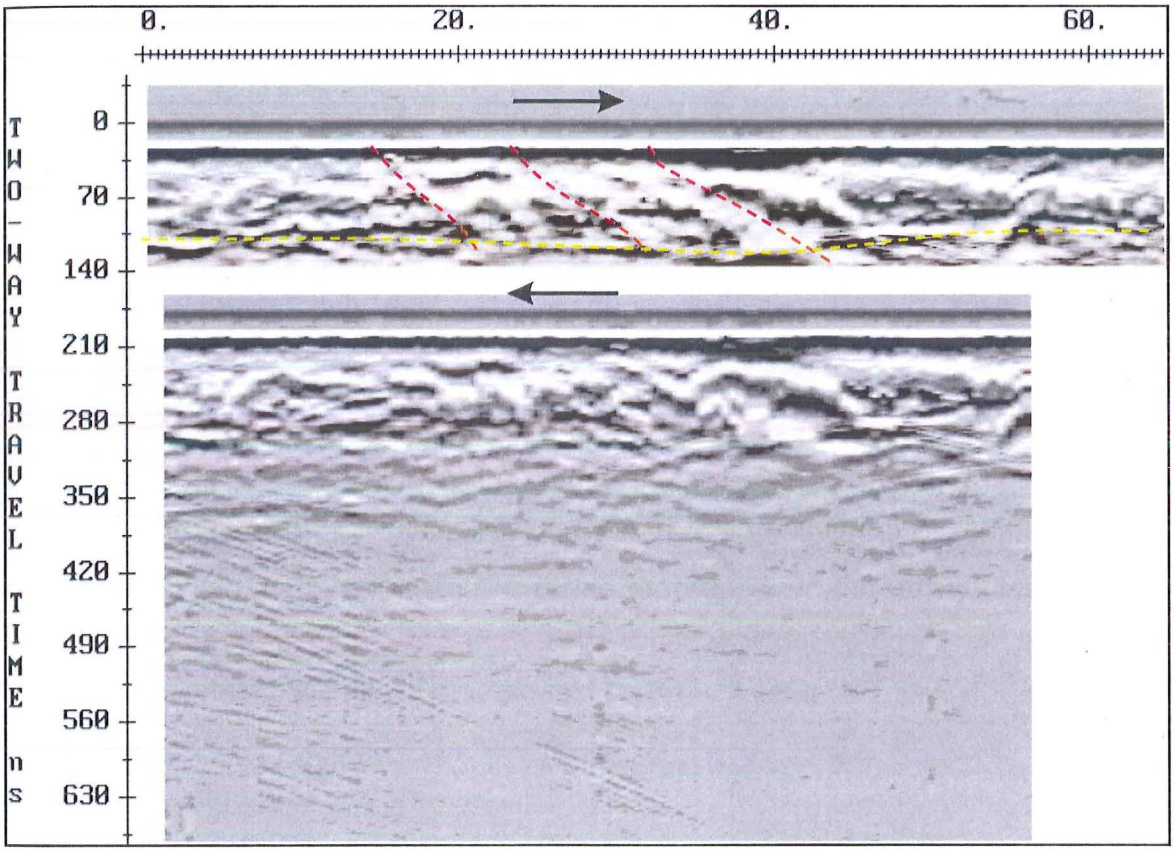


Figure 3-5: Data collected during GPR survey at Eureka Bend.
Top image is uphill run and bottom image is repeat downhill run. Apparent joints are shown in red and bedding in yellow.

Reproducibility of the data appears to be good, even accounting for the operator error that prevented workable data being collected. Features such as the apparent joints and bedding surfaces appear in the same position within both data sets, which suggests that the data itself was not corrupted.

3.3.3 Problems and Errors

Several problems were encountered during the running of this geophysical survey, as follows:

- Steep topography – the steep topography of the site made it challenging when using the equipment. It was difficult to establish accurate step sizes as the sled was pulled uphill, which could possibly affect the final outcome. The steep topography also made it difficult to access the survey line, and at one point the transmitter was dropped onto the road. Although it was later discovered that this did not do any damage to the transmitter, at the time this was not the case and the drop was seen as the reason for the unexpected results.
- Uneven terrain – the undulating and rock-scattered terrain meant that again it was difficult to maintain a constant step size or straight line, as occasionally the sled was required to negotiate large boulders.
- Incorrect initial set up of equipment – the fibre optic cables that connect the transmitter and receiver to the control box were plugged in the wrong way round at the beginning of the survey. This provided results that appeared upside down on the monitor. These were not detected until the first run was completed and were attributed to the drop earlier in the day. Attempts were made to correct the problem, but the cause was not detected and the second run was done with the same setup. This run yielded very similar results to the first.

3.3.4 Interpretation of GPR Survey

The results that were obtained during the GPR survey suggest that the traverse was conducted above limestone that was in-situ and therefore not related to the 'block'. The presence of possible bedding planes sub-parallel with the surface correlates well with nearby bedding that also dips in a similar orientation. If the GPR traverse was located above the 'block', sub-parallel bedding planes would not have been observed, as the bedding orientation is markedly different.

3.4 Emplacement of Limestone 'Block'

Several hypotheses have been developed to explain why the bedding immediately adjacent to Eureka Bend differs in orientation (by ~90°) compared to extensive limestone outcrops further to the north and also why the Arthur Marble is present on top of the 'block' when in-situ marble is located about 100 m up slope as mentioned in Section 3.2.1.

3.4.1 Change in Orientation

Fold Hypothesis

This hypothesis suggests that the block is in-situ, and that the observed orientation of its bedding is related to a southwest plunging anticlinal structure. Figure 3-6 shows how the strike of the bedding begins to wrap around from a north-south orientation to an east-west orientation as it approaches Eureka Bend. One explanation for this is that it is part of a south to southwest plunging anticlinal structure. Grindley (1980) and Jongens (1992) both show that Eureka Bend is located on the eastern limb of a north-south oriented syncline, and it is possible that it could be where the transition into an anticline occurs.

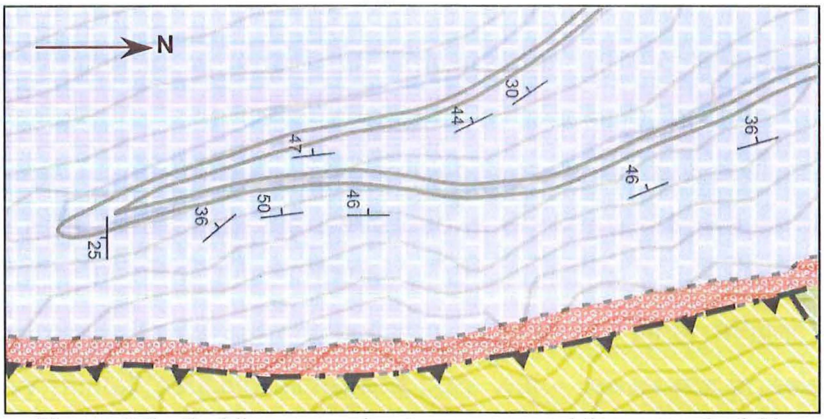


Figure 3-6: Bedding appearing to wrap around the nose of a fold.

Block Rotation Hypothesis

This hypothesis regarding the emplacement of the limestone block is that it was deposited by a simple block rotation related to cavities in the limestone beneath it. Dissolution of the limestone beneath the 'block' by groundwater flow would have led to the formation of cavities similar to the ones that would have formed the sinkholes located at the base of Takaka Hill (Figure 2-9). As the cavity expanded the support for the overlying block would have been decreasing until eventually the remaining underlying limestone would have been unable to support the 'block' and it would have back rotated into the cavity as shown by Figure 3-7. Thus rotating the strike of the bedding by about 90°.

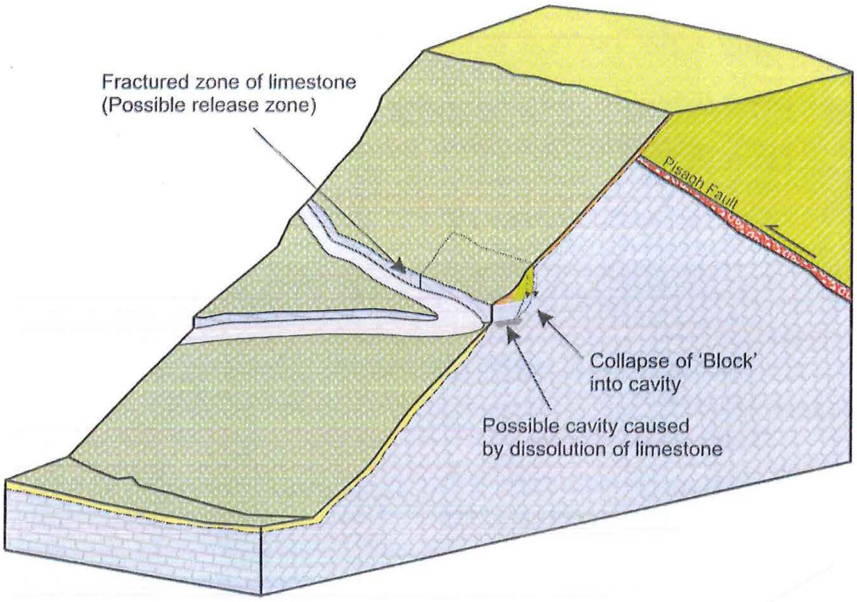


Figure 3-7: Block diagram showing how the block would have become emplaced at Eureka Bend. (Key for colours shown on Map 1).

Landslide Hypothesis

The second hypothesis regarding the emplacement of the limestone adjacent to Eureka Bend suggests that it was deposited by landslide mechanisms that saw it transported from further upslope and emplaced in its current position. The steep nature of the Pikikiruna Scarp, as discussed in Section 2.3.6, would have been the major contributing factor in the formation of the landslide that would have emplaced the limestone 'block' in its current position. Obviously other trigger mechanisms, such as heavy rainfall causing increased pore water pressures or seismic shaking, would have also been required to facilitate the rockslide. Figure 3-7 shows the likely source location of the landslide to be directly above Eureka Bend, with the flow path travelling through the corner and on downslope.

This landslide hypothesis suggests a 'block' or 'raft' of limestone detached from the fault zone and was picked up by a landslide that originated from further upslope. This block would have then been carried downslope before being deposited in its current position in the vicinity of Eureka Bend. The difference in the orientation of the bedding that is observed between Eureka Bend and outcrops further to the north may be accounted for by rotation of the limestone block during transportation by landsliding. This hypothesis also accounts for the presence of marble on top of the 'block' as it would most likely have already been in place before the 'block' was detached from the fault zone and thus simply travelled with it.

Globally there are examples of landslides that contain large intact blocks of rock within them. Although on a much larger scale, the Madison Canyon rockslide in 1959, caused by an earthquake, created a deposit containing 'house' sized blocks along with rock debris (Hadley, 1978).

Figure 3-8: Location of possible Eureka Bend landslide headscarp and flow path on 1989 air-photo.

3.4.2 Presence of Marble

Thrust Slice Hypothesis

This hypothesis suggests that a localised thrust slice related to the Pisagh Fault emplaced the Arthur Marble on top of the limestone 'block'. Figure 3-9 shows how marble would have been thrust along this localised fault and brought to the surface in the vicinity of Eureka Bend.

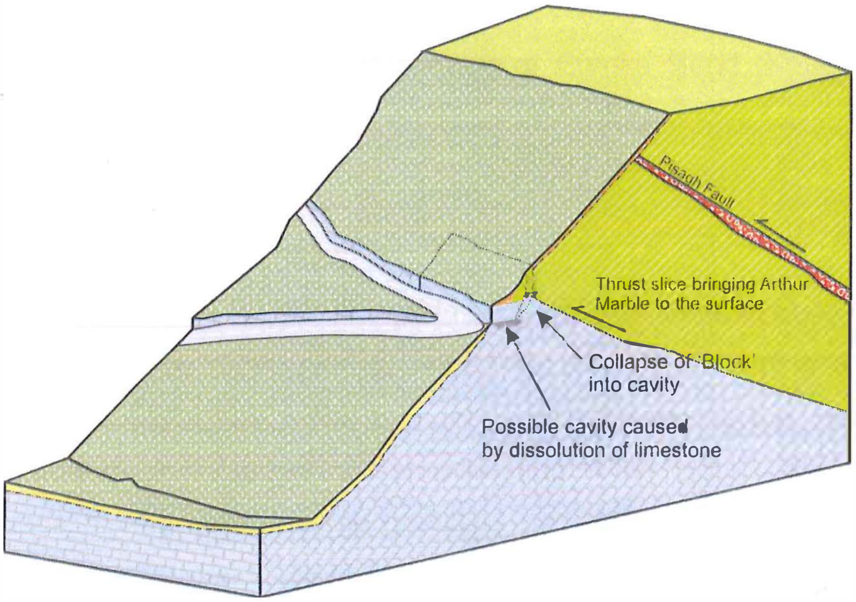


Figure 3-9: Thrust slice emplacement of Arthur Marble on top of Takaka Limestone. (Key for colours shown on Map 1).

Block Slide Hypothesis

From Map 1 it is possible to see that the bedding of the in-situ limestone dips in a west to southwest direction at an angle of 36° - 50°. It is therefore feasible that a marble slab could have slid along one of these weaker bedding planes into its current position. The original position of the marble would have been in the in-situ marble above the Pisagh Fault. A series of 'steps' were observed within the marble which were orientated sub-parallel to the strike of the bedding. These 'steps' may be formed by several slabs of marble resting on top of each giving the appearance of a step.

Possible triggering mechanisms for the failure may include increased pore water pressure or seismic shaking. If a large volume of water is able to penetrate into defects during a heavy rainfall or series of rainfalls then the increase in pore water pressure will see a reduction in effective stress which will increase the potential for failure which may be what happened in this case (Terzaghi *et al.,* 1996). The proximity of the failure to the Pisagh fault may also be responsible for the failure. Heavy shaking accompanied by steep terrain and possibly increased pore water pressure may have created the triggering mechanism required for failure (Wyllie and Mah, 2004). Various other landslides triggered by seismic activity have been recorded, for example in 1980 a 6.0 magnitude earthquake at Mammoth Lakes, California displaced a 20.4 t boulder that travelled 421 m before coming to rest and in 1983 an earthquake in Idaho displaced a 20.5 t boulder that travelled about 95 m which is similar to what may have happened at Eureka Bend (Kobayashi *et al.*, 1990).

3.5 Preferred Interpretation

3.5.1 Change in Bedding Orientation

The preferred interpretation for the change in bedding orientation at Eureka Bend is a block rotation caused by dissolution of underlying limestone forming a cavity into which the 'block' could rotate. The primary reason for this is the presence of a depression visible in air photos in the same location of the 'block'. There is also no visible evidence of any large historic landslide path down which the 'block' could have been transported or landslide deposits in the test pits below Eureka Bend.

It is also unlikely that the fold hypothesis explains how the limestone immediately adjacent to Eureka Bend came to be emplaced there, as no anticlinal structure has been mapped within the vicinity of the bend. Field mapping did not produce any further evidence to suggest that one is present, for example, no nearby limestone outcrops exhibited similar orientations.

However, due to the lack of subsurface information in this area it is difficult to make a highly accurate interpretation.

3.5.2 Presence of Marble

The preferred hypothesis for the emplacement of marble on top of the limestone 'block' is a detachment of a slab or slabs of marble from above the fault zone, which would have then been transported along a bedding surface before coming to rest on top of the limestone adjacent to Eureka Bend.

It is unlikely that it would have been emplaced by a thrust slice because of the very localised extent of the marble. A much larger lateral extant of marble would have been expected if a thrust slice emplaced the marble. Field mapping and the GPR survey did not detect any marble directly to the north of the marble on top of the limestone 'block'. Marble would also be expected to outcrop further upslope and again this is not seen.

3.6 Dimensions of the Interpreted 'Block'

From field observations the size of the block was determined to be approximately 60 m long × 25 m wide, however the depth of the block is difficult to ascertain as no subsurface investigations have been done that provide any information in that regard. Therefore a volume cannot be accurately established. Figure 3-10 shows the extent of the block in plan view.

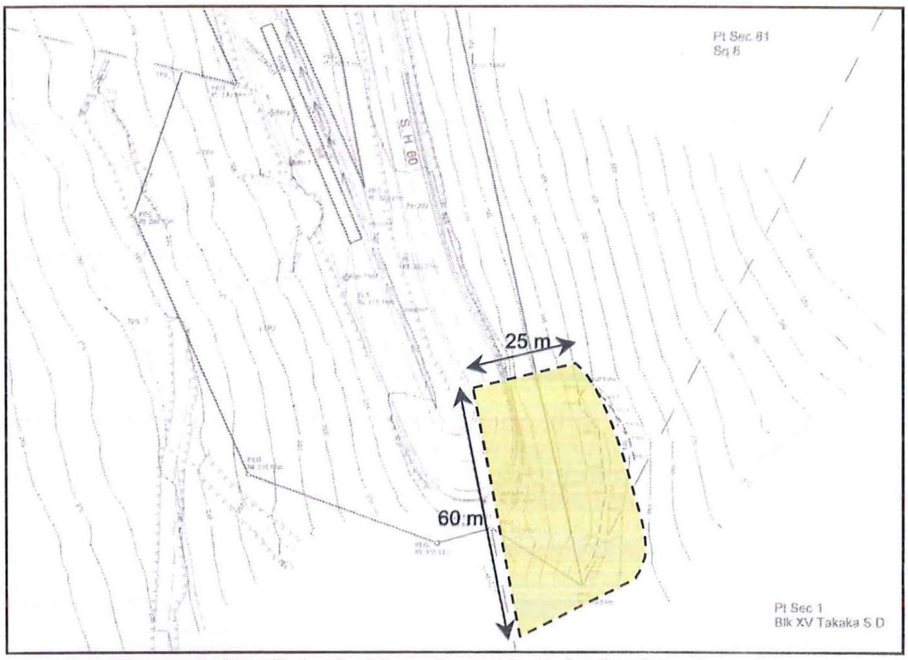


Figure 3-10: Extent of limestone block (yellow) in plan view.

3.7 Geotechnical Issues Related to the Road Cutting

Currently there are several geotechnical issues associated with the current geometry of Eureka Bend and further issues can be expected if the proposed widening goes ahead. The issues that need to be addressed are:

- Current cut stability – the stability of the current road cutting needs to be assessed to determine its long term stability should the widening proposal not go ahead. Kinematic analysis will be done on scanline and defect data using the Rockscience computer program DIPS to assess the current stability.
- Rock strength – the strength of the rock in the road cutting needs to be assessed to determine whether or not it is suitable as a fill material for the engineered earth embankment. Point load testing of samples taken from the field will be carried out in the University of Canterbury's rock mechanics laboratory to determine strength parameters.
- Rock durability – the rock also needs to be assessed for its durability when exposed to wetting and drying cycles. This is done by conducting a slake durability test which simulates wetting and drying of samples in a controlled environment.

Chapter Four

Rock Characteristics of the Proposed Cut

4.1 Introduction

As mentioned in Section 3.7 there are several geotechnical issues that need to be addressed in regards to the road cutting adjacent to Eureka Bend, both in its current geometry and also in its proposed geometry. This section discusses the stability of the current road cutting, as well as rock strength and durability parameters that will be relevant should fill be required for the proposed engineered earth embankment. Rockfall analysis has also been conducted on the current alignment to determine susceptibility to rockfall hazards, and any consequent mitigation requirements.

4.2 Rock Strength Testing

4.2.1 Point Load Testing

Point load testing was carried out on sawn blocks of limestone and marble that were collected from adjacent to and above the road cutting at Eureka Bend. The point load test is a convenient method to ascertain an estimation of rock strength and subjects a rock sample to a force that is focused through two shaped platens. The pressure (kN) required to fail the block between the two platens is then recorded and along with the width (W) of the sample and the distance between the platens (D) it is possible to calculate the point load strength index (I_s) for the rocks tested. This then reported as $I_{s(50)}$ (MPa) which corrects the I_s values to a standard D value of 50 mm using a formula for size correction (F). All testing was done in accordance with guidelines set out in Franklin *et al* (2007a).

Samples of both the Arthur Marble and the Takaka Limestone were tested using this method to determine their suitability as fill in the proposed engineered earth embankment. The data also provided an understanding as to the rippability of the rocks, which will ultimately determine the means of excavation that will be used to remove them. All results from the point load testing are included in Appendix 5. The mean $I_{s(50)}$ results for all three tests have been converted to obtain an unconfined compressive strength (σ_c) using a simple assumption that sees the $I_{s(50)}$ values multiplied by a factor of 24 (Wyllie and Mah, 2004).

The Takaka Limestone was tested with the platens oriented both parallel and perpendicular to bedding to determine if there is any variability in strength due to anisotropy. A summary of the results is shown in Table 4-1.

Table 4-1: Summary of Point Load Results

Rock Type	Point Load Result (MPa)	UCS Value (MPa)
Arthur Marble	3.83	92
Takaka Limestone - ⊥ to bedding	2.34	56
Takaka Limestone - = to bedding	1.71	41

4.2.2 Rippability

The point load results that were obtained for the marble and the limestone have been used to determine the rippability of the materials and also their suitability as a fill material. Figure 4-1 shows the rippability of the two samples to be 'very hard' to 'blasting required' when a mean discontinuity spacing of 1 m – 2 m is used. As the excavation will be done on a near vertical face the 'perpendicular to bedding' limestone results should be used, as all excavation will occur perpendicular to the bedding. However, because of its location blasting is recommended because access for machinery is limited and all point load indices are towards the upper limit for mechanised excavation.

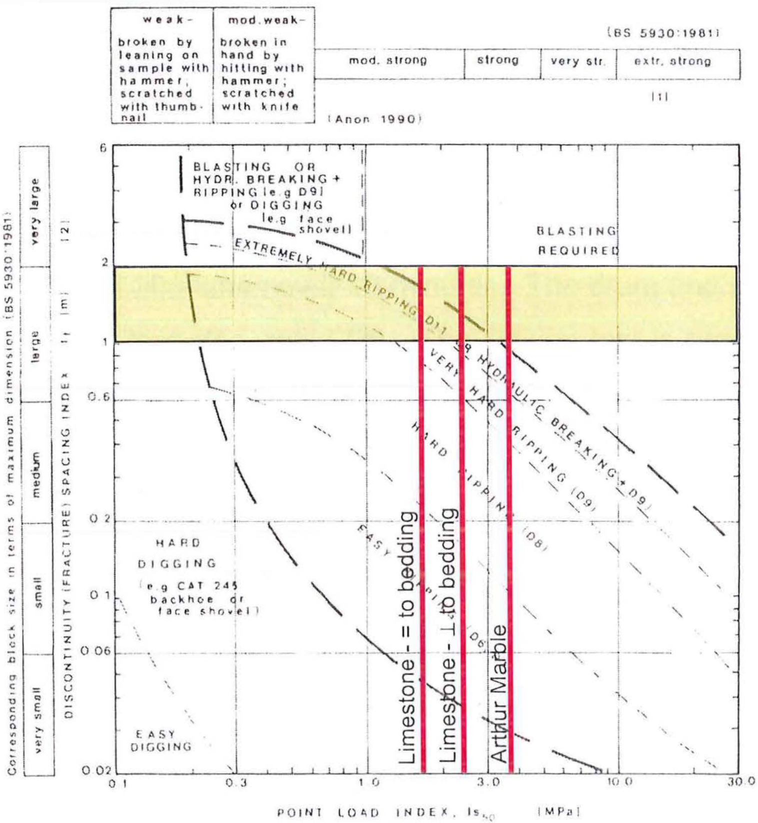


Figure 4-1: Rippability of rock as a function of mean spacings of discontinuities and compressive strength. Yellow box shows mean discontinuity spacings and red lines show point load index for each material tested (adapted from Smith, 1999).

4.2.3 Suitability of Rock Strength for use as Fill

The point load results and the subsequent conversion to UCS values indicates that both the limestone and the marble are adequate materials for use as fill in the reinforced earth embankment. Using the equation:

$$P = \rho g h$$

Where P = pressure (Pa)
ρ = density of the material (kg/m^3)
g = acceleration due to gravity (9.81 m/s)
h = height of overburden

It can be shown for a density of 2700 kg/m^3 and a overburden thickness of 11 m (from GHD, 2008) that the overburden stress is ~0.3 MPa, which is much less than the UCS value obtained for the limestone of ~40 MPa when tested parallel to bedding. Even with vehicle loads taken into consideration, the limestone and marble will still have enough strength to be used as fill.

4.3 Rock Durability Testing

4.3.1 Slake Durability Test

To assess a rock's resistance to weakening and disintegration under standardised conditions of wetting and drying a slake durability test can be conducted. The method involves placing 10 roughly rounded lumps of sample weighing about 40 - 60g each in the drum. This is then oven dried at 105°C and the mass of the drum and the sample is then recorded (A). The drum is then mounted in the slaking fluid and the drum is rotated 200 times over 10 minutes. The drum and samples are then re-dried and the mass recorded again (B). The slaking test is repeated; dried then drum and sample are re-weighed (C). The drum is then cleaned and it's mass recorded (D). Using the equation below it is then possible to calculate the slake durability index for each test.

$$\text{Slake durability index } (I_{d2}) = ((C-D)/(A-D)\times 100$$

The slake durability index is the percentage ratio of final to initial dry sample masses. If the index is low then the rock will be susceptible to degradation (Wyllie and Mah, 2004). All testing was done in accordance with guidelines set out in Franklin *et al* (2007b).

4.3.2 Results

From the rock samples collected form Eureka Bend, one sample of marble and one sample of limestone were prepared for slake durability testing. The results are shown in Table 4-2.

Table 4-2: Slake Durability Index (I_{d2})

Lithology		Marble	Limestone
Initial weight of dry sample and lid-less drum (g)	A	1905.7	1885.5
Weight of dry sample and lid-less drum after one cycle (g)	B	1904.9	1883.3
Weight of dry sample and lid-less drum after second cycle (g)	C	1904.5	1882.2
Dry weight of clean drum (g)	D	1374.8	1369.9
C – D		529.7	512.3
A – D		530.9	515.6
Slake durability index I_{d2}		**99.8**	**99.4**

The high slake durability indices of both the marble and the limestone, 99.8 and 99.4 respectively, suggests that both materials will not be particularly susceptible to degradation from wetting and drying cycles. When considered with strength data both materials will be suitable as fill in the reinforced earth embankment that is proposed beneath Eureka Bend.

4.4 Stability of Current Road Cutting

4.4.1 Scanline Sampling and Modelling

Scanline sampling was the method used to obtain data for defect and slope stability analysis. It involved laying out a string line along the face in question and recording any defects encountered along the line. During the field component of this project a 30 m scanline survey was conducted along the current road cutting. Figure 4-2 shows the location of the scanline and the data that was collected is included in Appendix 5. A defect survey was also conducted on the road cutting and that data has been be included in the analysis.

The computer analysis of the data that was collected was done using Rocscience software programme, DIPS. DIPS is used for stereographic projections of the data from which it is possible to determine sets of bedding and other defects, as well as doing kinematic analysis on the data sets to determine stability with relation to specific cutting orientations.

Figure 4-2: Location of scanline survey at Eureka Bend.

4.4.2 Reproducibility of Data

When defect surveys are conducted it is important to collect as many defect points as possible. The reason for this is that the bigger the data set the more accurate any analysis will be. In general a dataset of 300+ points should be obtained before any stereonet analysis is conducted.

The scanline dataset that was collected during the fieldwork component of the research only consisted of 24 data points, therefore it was important to try and obtain more data to improve the accuracy of any results. GHD had previously carried out a defect survey along the same section of road cutting therefore their data has also been analysed. Unlike a scanline survey, they only sampled any discontinuities that they could get an accurate reading on. Their dataset only contained 14 points, but by comparing the two datasets it is possible to see how reproducible they are and whether they can be combined to form a larger dataset.

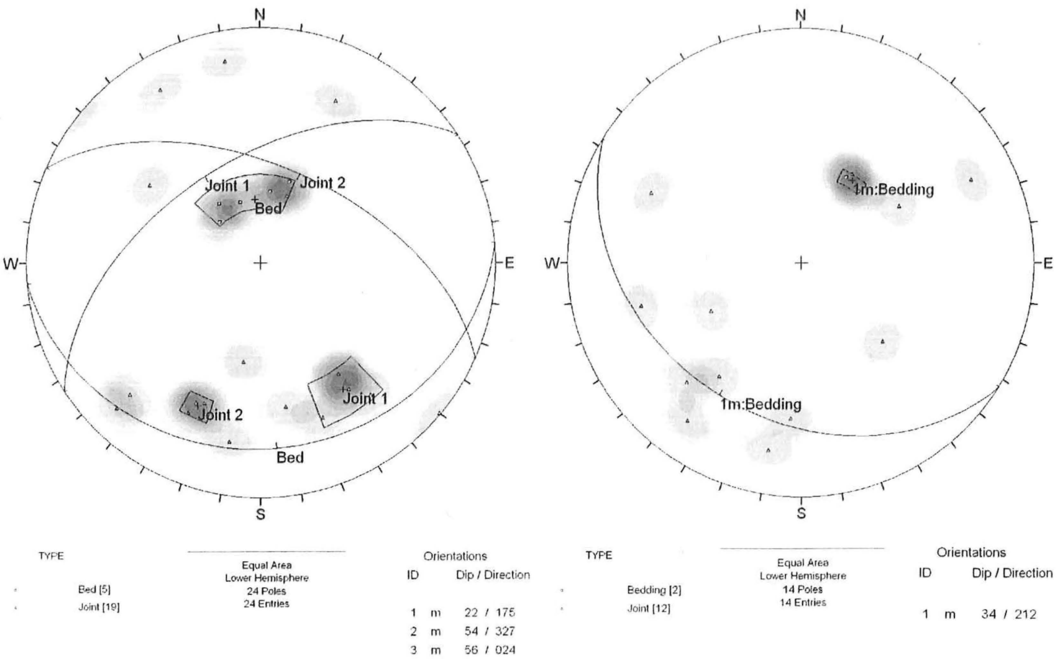


Figure 4-3: Comparison of defect data.
Left figure is my scanline data and the right is GHD's defect data.

From Figure 4-3 some correlation between the two data sets is evident, most noticeably the bedding orientation. Both sets of results show bedding that has a dip direction of south to south west which is what was expected. However, the joint sets are less reproducible as the GHD dataset is too small to create a joint set window with. Although, just from studying the two figures it is possible to see a small concentration of joints towards the southwest within GHD's dataset, which roughly corresponds with Joint 2 of the scanline data. Therefore, it is feasible to combine the two datasets to combine a slightly larger one of 38 points, which should enable a more accurate analysis to be completed.

4.4.3 Kinematic Analysis

Kinematic analysis was conducted on data sets within DIPS to determine the stability of specific cut face orientations. It is possible to assess several failure modes including, planar, wedge and toppling failures. The internal angle of friction (φ) for all failure modes discussed in this section has been set between 35 - 45°, which is a range adapted from Naser (2004) who based it on Goodman (1980) and Bowles (1996). In this section all figures for kinematic analysis use an internal friction angle of 35° which is the lower end of the range mentioned earlier and is considered appropriately conservative. This applies for all modes of failure and all results will be included in Appendix 3.

Planar Failure

The requirements for planar failure taken from Wyllie and Mah (2004) are as follows:

- The failure plane must strike parallel or nearly parallel to the slope face (within ~20°)
- The failure plane must daylight in the slope face.
- The dip of the failure plane must be smaller than the dip of the slope face.
- Release surfaces that provide negligible resistance must be present.

Figure 4-4 below shows how these requirements are used to determine whether there is potential for planar failure along a specific face orientation, in this case the current Eureka Bend road cutting. The crescent of yellow defined by the angle of internal friction and the daylight envelope of the quarry face highlights poles to defects that may have the potential to fail along a plane.

Very few poles plot within the failure envelope, which suggests that the face is relatively stable and is not prone to planar failures along any defect surfaces. Of the three poles that do plot within the envelope all are related to joints, which means that there is the potential for planar failure. However, it would only be along one joint surface and is unlikely to promote further instability of the face or cause more than an inconvenience to roading crews who have to clean it up.

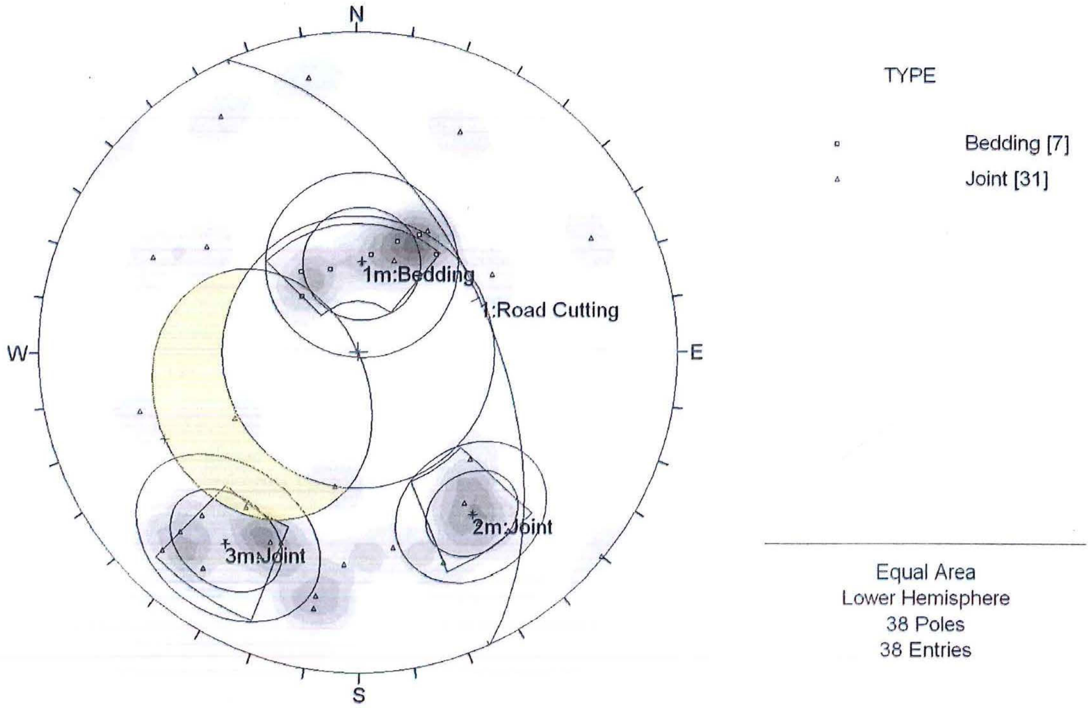


Figure 4-4: Kinematic analysis of road cutting for planar failure potential. Internal angle of friction equals 35°. The yellow zone encompasses poles that have the potential to fail.

Toppling Failure

The structure conditions required for toppling failure, taken from Wyllie and Norrish, (1994), are as follows:

- The strike to the defect must be approximately parallel to bedding. A range of ±30° was used for this analysis.
- The dip of the layers must be into the slope face.
- In order for interlayer slip to occur, the normal to the toppling plane must have a plunge less than the inclination of the slope minus the friction angle of the surface.

Figure 4-5 shows the kinematic analysis that was done for the current road cutting orientation of 66 / 056. Any poles that lie within the yellow crescent represent defects that have the potential to fail given the necessary frictional requirements. For the current orientation of the road cutting there is very little chance of toppling failure, as only two poles have plotted within the failure envelope. This may just result in ravelling of the face as small pieces of limestone detach from the face. No larger joints sets are likely to cause significant toppling failures.

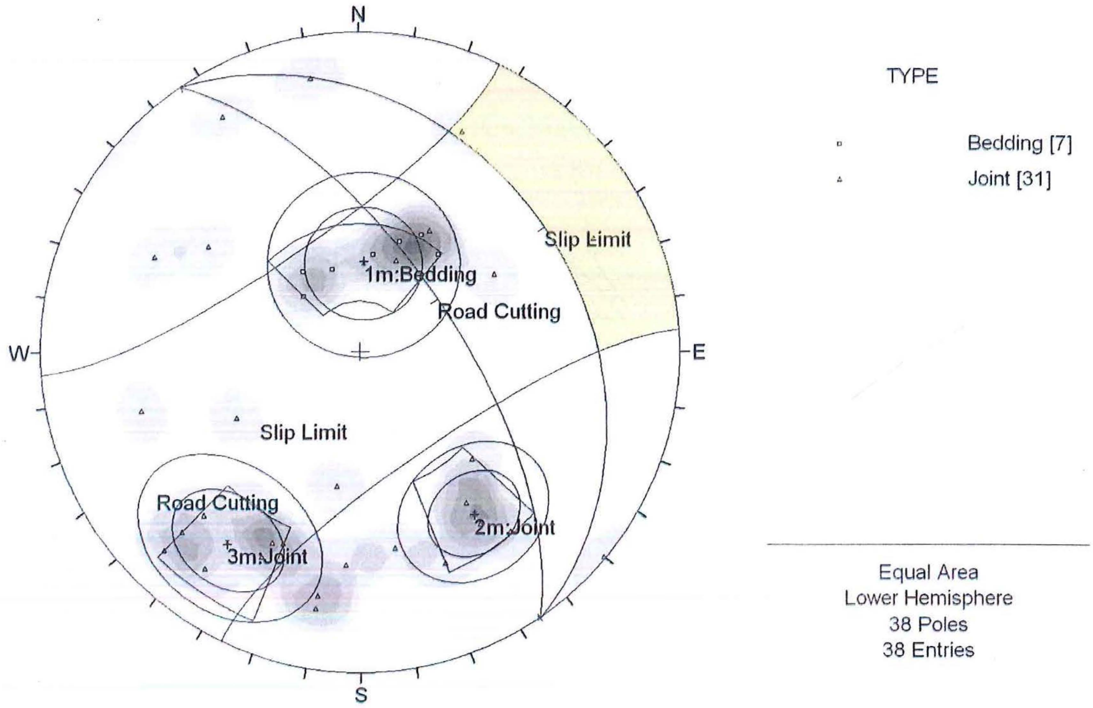


Figure 4-5: Kinematic analysis of road cutting for toppling failure potential. Internal angle of friction equals 35°. The yellow zone encompasses poles that have the potential to fail.

Wedge Failure

The structural conditions that are required for wedge failure, taken from Norrish and Wyllie, 1994, are as follows:

- The trend of the line of intersection must be approximate to the dip direction of the slope face.
- The plunge must be less than the dip of the slope face, which means the line of intersection will daylight on the slope.
- The plunge of the line of intersection must be greater than the angle of internal friction of the surface.

The yellow crescent shown in Figure 4-6 indicates the area on the stereoplot that is prone to wedge failure. If any two planes to defects intersect within this zone then there is a possibility of wedge failure. As no planes to bedding or joints intersect within this zone the face can be considered stable. There may still be the possibility of small-scale wedge failures occurring along defect intersections that were considered too insignificant to include in a joint set or were sub-parallel to face.

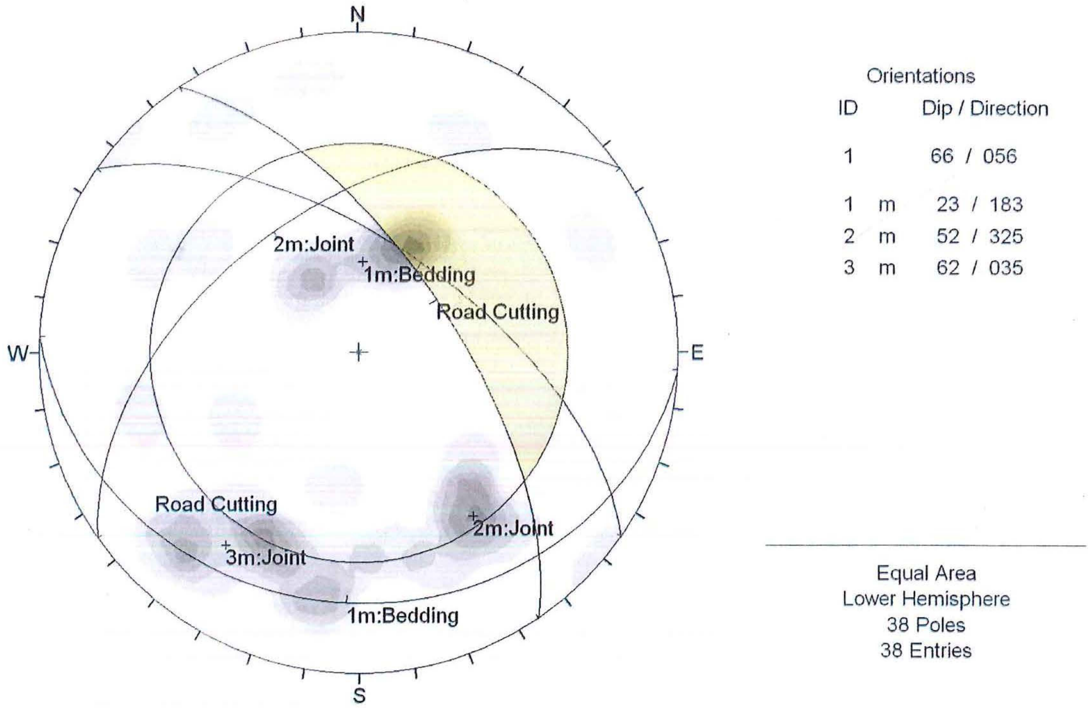


Figure 4-6: Potential for wedge failure in defects in the road cutting.
The yellow zone encompasses intersections of planes that have the potential to fail.

Stability Assessment

The results obtained by kinematic analysis of the scanline and defect survey data that was collected for the road cutting at Eureka Bend suggest that the face in its current orientation (66 / 056) is relatively stable. The results that were obtained for all three failure modes suggest that the face is not likely to be affected by any of these mechanisms and that any failures that do occur will be nothing more than ravelling of loose material from the face. It is accepted that the dataset is limited, but this is a relatively massive rock mass with widely spaced defects that are not obviously sheared or otherwise indicative of past movements.

4.5 Rock Fall Hazard Assessment of Current Setting

The highly fractured and semi-spherical nature of the marble higher upslope means that the road and motorists using it may be at risk from rockfalls. The lower slopes adjacent to Eureka Bend show evidence of previous rockfalls in the form of rocks that have rolled down from further upslope, as shown by Figure 4-7. There is the potential that one of these rocks may impact on the roadway, therefore a rockfall hazard assessment of the current alignment of Eureka Bend was done using the Colorado Rockfall Simulation Program (CRSP) to determine the susceptibility of the current roadway to rockfall hazards from boulders released higher upslope. The rockfall parameters that were used were obtained from the user manual written by Pfeiffer *et al.* (1995).

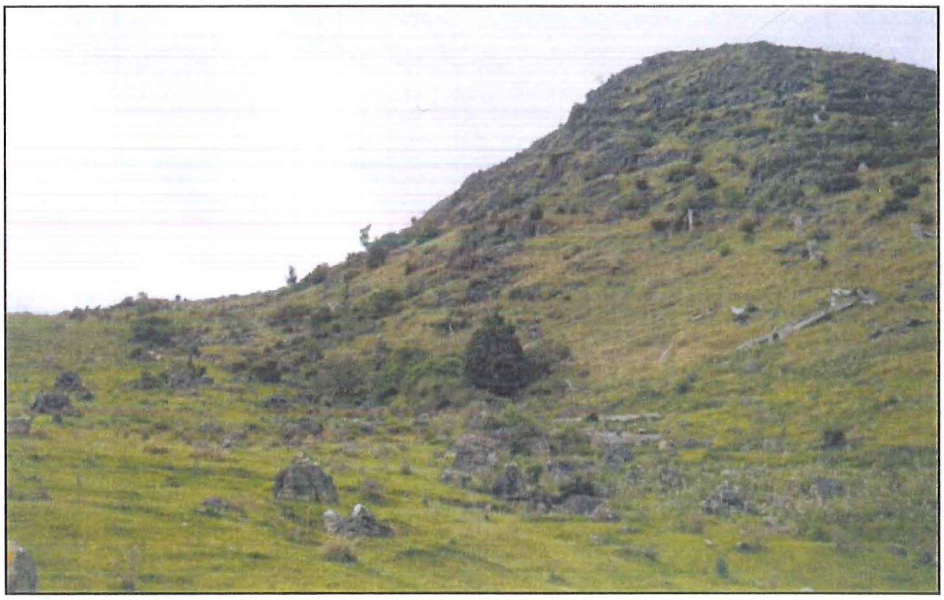


Figure 4-7: Evidence of previous rockfalls north of Eureka Bend

A simulated rockfall comprising of 500 1 m diameter rocks was released between 30 m and 60 m above the roadway. The computer program then modelled their likely travel paths, including whether they bounced or rolled based on input parameters set by the user (refer to Appendix 4). From Figure 4-8 it is possible to see that many rocks would make it onto the roadway, which is a concern that must be addressed whether or not the widening of Eureka Bend goes ahead.

Statistical analysis of the simulated rockfall showed that of the 500 rocks released 10 made it to the roadway, which is only 2% of all the rocks released. The heavy vegetation that was factored in directly above Eureka Bend played an important role in reducing the number of rocks passing, from 36 at Analysis Point 1 to just 10 at Analysis Point 1, however although the probability of a rock reaching the roadway is low it is still obviously feasible and careful management of the vegetation is needed to provide protection from rockfall hazards. Additional mitigation measures may be deemed necessary as they could be incorporated into the planned widening.

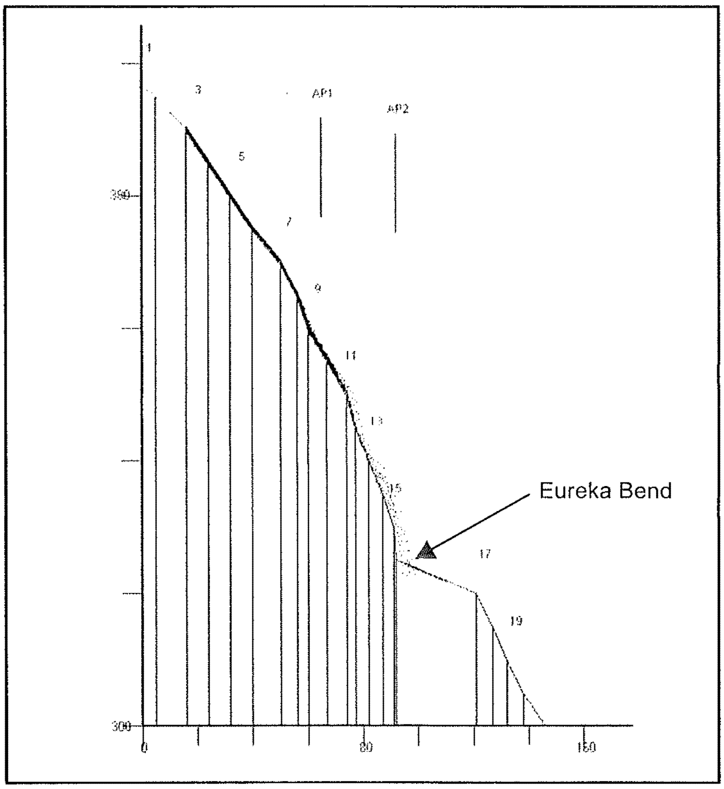


Figure 4-8: Output from CRSP for current profile at Eureka Bend. AP = Analysis Point. Vertical exaggeration 1V : 2.7H.

4.6 Synthesis

The rock mechanics testing that was done showed that both the Arthur Marble and the Takaka Limestone would be suitable materials to use as fill in the proposed reinforced earth embankment, both in terms of strength and durability. They are also strong enough to stand in a near vertical face such as the proposed road cutting.

The kinematic analysis of the available defect data for the current face orientation showed that the face is relatively stable in its current setting for all three failure modes tested, planar, toppling and wedge. However the rockfall analysis that was done using CRSP indicated that Eureka Bend is currently susceptible to rockfall hazards therefore mitigation measures will need to be considered in any design proposals put forward regarding the widening of the corner.

Chapter 5

Engineering Geology Assessment

5.1 Introduction

This chapter addresses design considerations relevant to the widening of Eureka Bend. If the geometric realignment of Eureka Bend goes ahead as proposed in Option 2 the turning radius of the corner will be increased to 15 m which will entail a cut of 23 m (in plan) from the current apex of the corner. This new alignment will allow a B-train to negotiate the corner without having to cross the centreline. Naturally, the steep topography is a cause of concern as any new cut will create a much higher cut face, which then presents new challenges regarding water control, rock mass stability, and rock fall hazard mitigation. One of the main aims of this project was to create a feasible design for the proposed widening of Eureka Bend. Two different designs have been created to address the issues involved with the expected high cut faces. Design 1 involves a single 23 m high cut batter set at an angle of 4V : 1H while Design 2 employs an intermediate bench at a height of 15 m which acts to lower the individual height of the batters to no more than 15 m each. It to will use a batter angle of 4V : 1H.

5.2 Slope Design 1

5.2.1 <u>Design</u>

Design 1 adapts a cut batter set at an angle of 4V : 1H (76°) for the full height of the cut with no intermediate benching. Figure 5-1 shows how the cut batter at an angle of 76° creates a cut face 25 m high. The top of the cut is tapered into the angle of the original ground to reduce the risk of rockfall from the top of the slope. A rock fence would be placed at the top of the slope to provide protection to the roadway below from rockfall hazards originating above the cut.

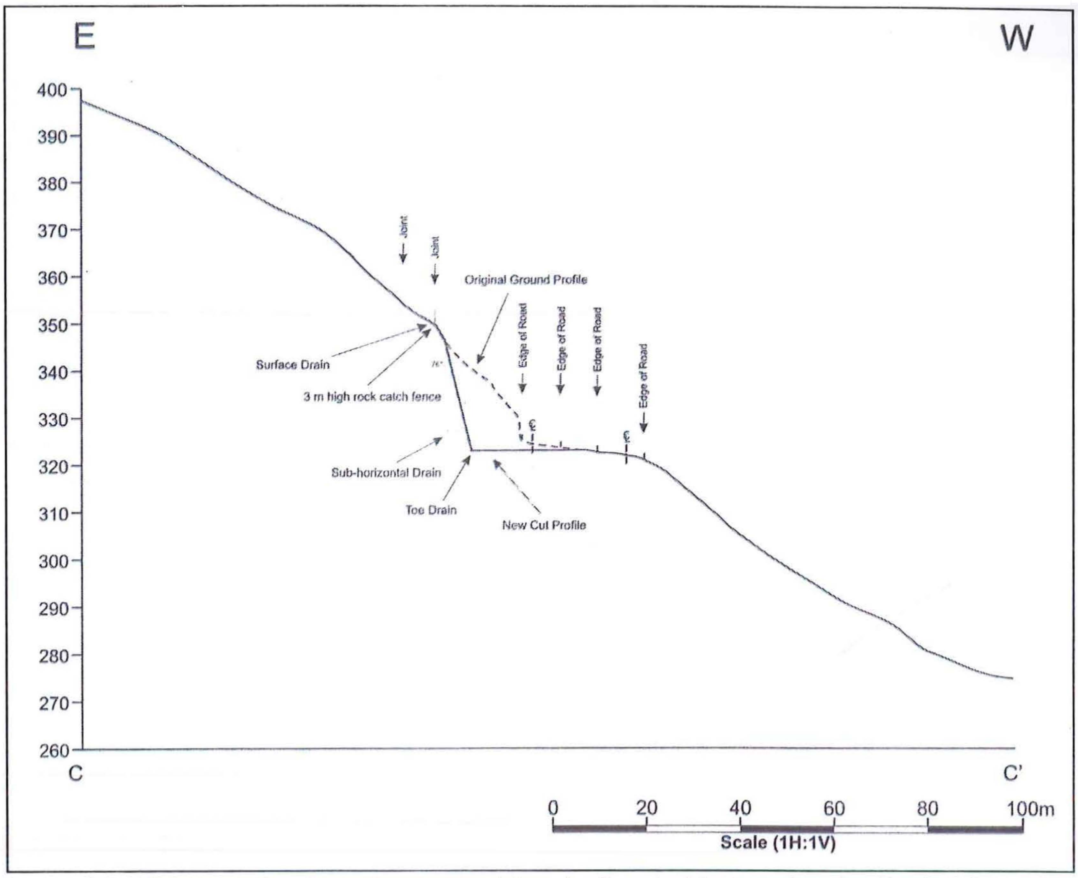


Figure 5-1: Cross section through proposed Eureka Bend widening showing Design 1 features.

5.2.2 Volume of Material Generated

Figure 5-2 shows an approximate area of material that will be excavated from the face adjacent to Eureka Bend. The volume of excavated material was calculated to be approximately 8000 m^3 by breaking the shape down into it's geometric components and calculating their area multiplied by the height of the cut.

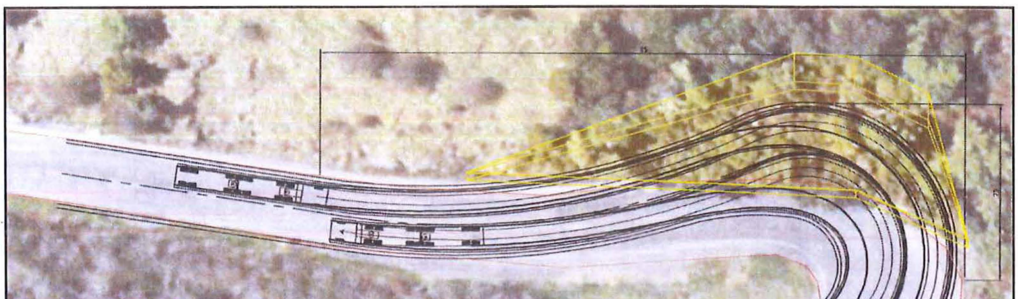


Figure 5-2: Approximate extent of the Design 1 cut required for the widening of Eureka Bend.

5.2.3 Rock Mass Stability

From the rock strength assessment done on the Takaka Limestone in Section 4.2.1 it has been calculated that the rock is strong enough to stand at 76° to a critical height of 1500 m+ if no discontinuities are considered. The stability assessment done on the face in Section 4.4 also indicates that the face is stable in its current setting because of the wide spacing and orientation of observed defects in road batter. Therefore, the limestone will be able to stand safely in a 25 m cut face providing presently undisclosed adverse discontinuities are not encountered as the excavation progresses. The biggest issue for a slope this high will be the joint release of small blocks due to weathering processes, assuming no penetrative joints daylight the cut face. Mitigation meausres are discussed in Section 5.2.3.

However, as the exact conditions behind the current face are unknown without drilling or other investigations it is not possible to determine the proposed cut face's stability with regards to jointing and bedding defects.

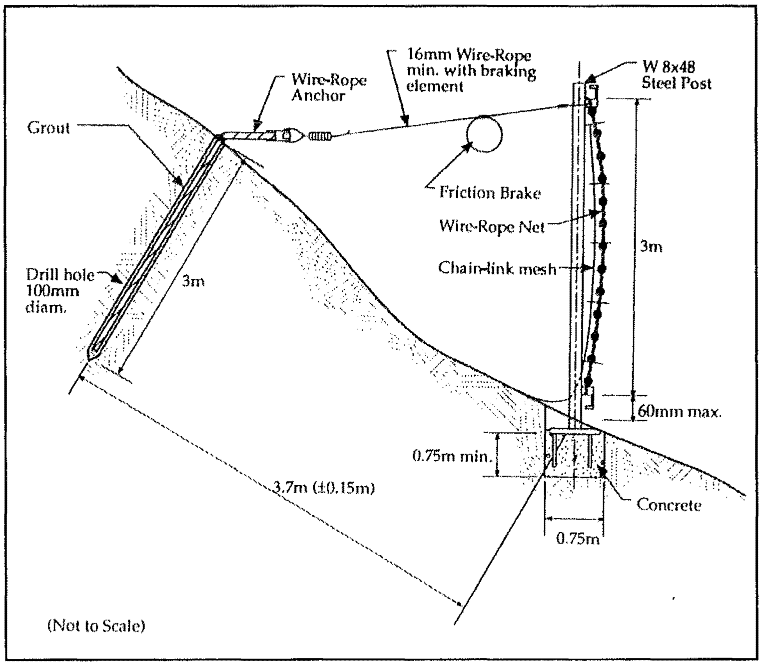


Figure 5-3: Design details of a woven wire-rope rock catch fence. (From Wyllie and Norrish, 1996)

5.2.4 Rockfall Mitigation

For Design 1 a 3 m high rock catch fence will need to be built at the top of the face to catch and prevent any large rocks from falling onto the road below. The suggested fence is a woven wire-rope fence which are nets with high-energy absorption capacity constructed with woven wire-rope mesh or ring mesh (Figure 5-3; Norrish and Wyllie, 1996). Tests have shown that they are capable of stopping rocks with impact energies of 3000 kJ without sustaining too much damage (Smith and Duffy, 1990 and Duffy and Haller, 1993). This equates to a rock weighing 3000 kg travelling at a velocity of 23 m/s (Wyllie and Norrish, 1996).

This type of fence would be best suited at this location as there is the potential for large boulders to be released from the highly fractured Arthur Marble further upslope. The fence would be built on a berm 2 m from the top of the cut face. The berm acts to increase the height of the fence as well as a ditch for rocks to accumulate in without them leaning on the fence, which has the potential to reduce the effectiveness of the fence. Machinery can then be brought in to clear the ditch whenever rocks start to fill it, which lowers the risk of the fence becoming compromised. Figure 5-4 shows the likely rockfall hazard related to the design presented above. Before a rock catch fence is installed 12 of the 500 rocks released reach the roadway. After the 3 m high rock catch fence is installed no rocks are able to pass.

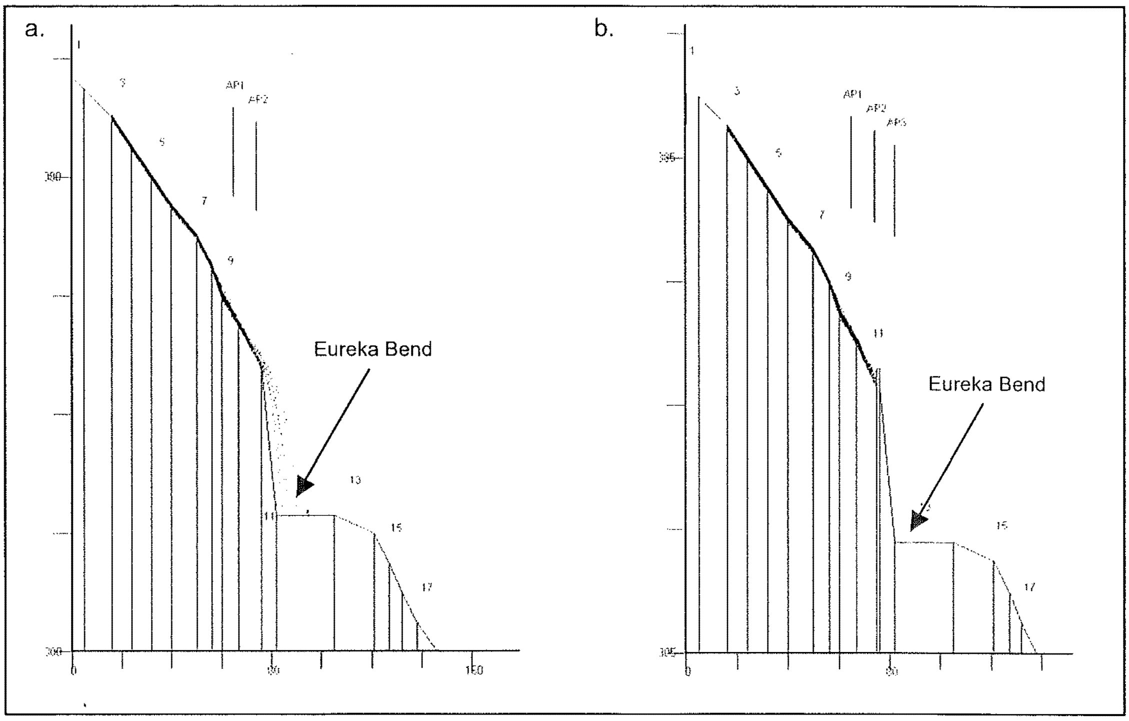


Figure 5-4: Output from CRSP for the Design 1 profile.
a. is without a rock catch fence and b. has a rock catch fence and the head of the cut face. Vertical exaggeration = 2.7V : 1H. Boulders simulated are spherical and have 1 m diameter.

Depending on the stability of the cut face itself, various other mitigation measures will also have to be taken such as rock reinforcement and rock removal. Following Wyllie and Norrish (1996) these could include rock reinforcement.

- Rock bolting of potentially loose rocks using tensioned bolts.
- Rock dowels – reinforced steel drilled into underlying rock installed to provide passive shear resistance to sliding and are used to support slab of rock 1 m to 2m thick.
- Shotcrete – good for protecting closely fractured or degradable rock. Drain holes must be drilled through the shotcrete to reduce build up of water.
- Shot in place buttresses – blasting of a failure surface to increase the friction angle.

And rock removal.

- Resloping and unloading zones of rock that may be degraded making them rockfall hazards.
- Trimming – controlled blasting of overhanging rocks on a cut face.
- Scaling – is the removal of loose rock, soil and vegetation from the face usually by hand.

5.3 Slope Design 2

5.3.1 Design

Design 2 differs from Design 1 because it incorporates an intermediate bench into the design. The batter angle will still be at 4V : 1H (76°), but a 6 m wide bench has been included at a height of 15 m, see Figure 5-5. This will reduce the height of individual cut batters, provide a drainage berm above the road, increase stability and safety of the cutting, and allow for easier maintenance. The 6 m width was chosen because it means that the bench would be wide enough for machinery to access it to remove any debris that may be accumulating. The bench itself will have a gradient of ~5° into the hill which will act to channel surface runoff into a surface drain that will be built against the cut batter at the back of the bench. This drain will prevent water penetrating into the rock mass of the cut, thus increasing pore water pressures and potentially increasing the likelihood of instability. The gradient will also act to hold the layer of aggregate used for lowering the normal coefficient of restitution in place.

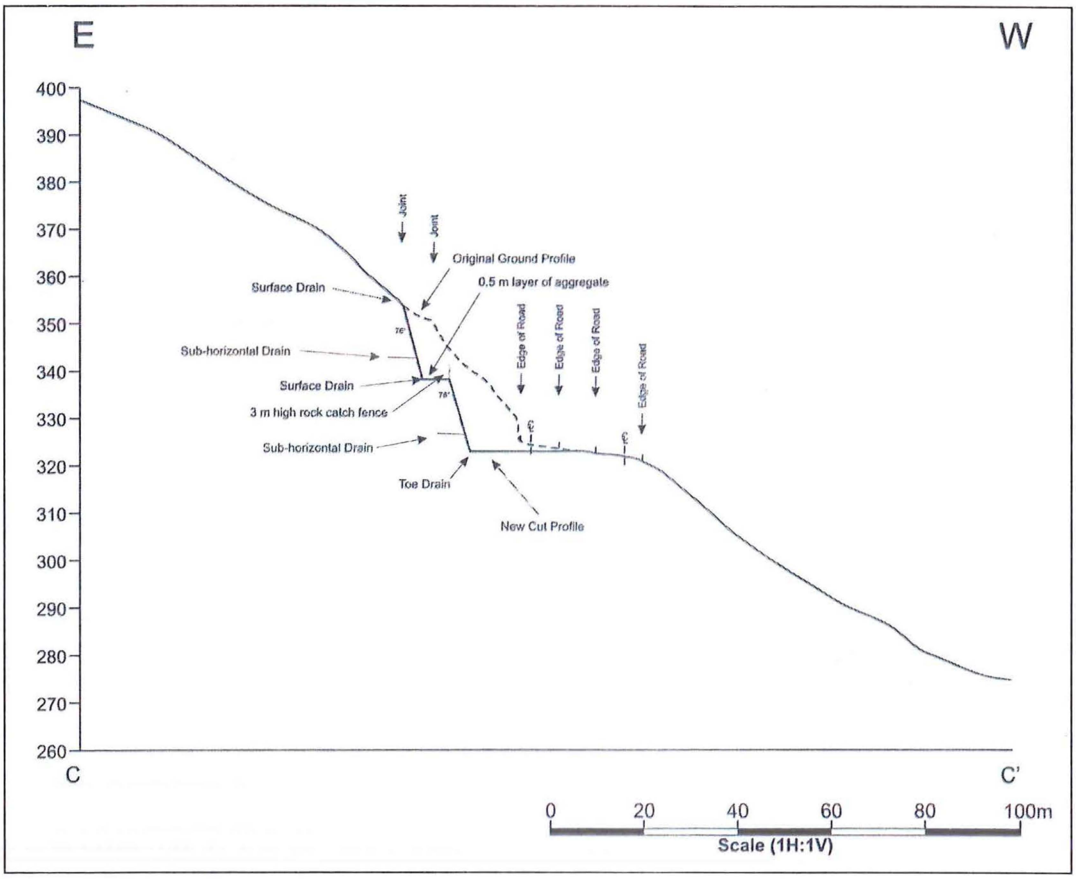


Figure 5-5: Cross section through proposed Eureka Bend widening showing Design 2 features.

As with Design 1, the volume of material to be excavated was calculated by breaking the shape down into it geometric components and calculating their area multiplied by the height of the cut. For Design 2 the volume that will need to be excavated is approximately 12 000 m^3, which is a 50% increase on Design 1. Figure 5-6 shows the extent of the cut proposed for Design 2.

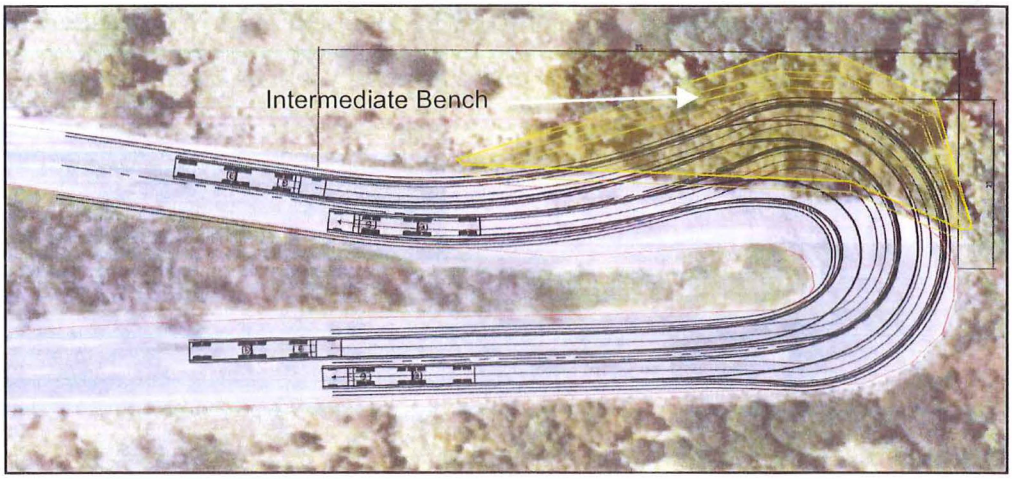


Figure 5-6: Approximate extent of the Design 2 cut required for the widening of Eureka Bend. Adapted from GHD, 2007.

5.3.2 Rock Mass Stability

As mentioned in Section 5.2.2 the critical height for the limestone based on the UCS values obtained from point load testing is 1500 m+ without considering discontinuities. Therefore it will be able to stand at 76° in the profile shown for Design 2 if similar discontinuities to the ones encountered in Section 4.4 are found.

5.3.3 Rockfall Mitigation

The rockfall mitigation measures that will be used for Design 2 are similar to Design 1 including the use of a rock catch fence and rock reinforcement and removal where needed. The addition of the intermediate bench to the design means that a greater level of protection can be offered against rockfall hazards, as the bench can be covered in a 0.5 m to 1 m thick layer of crushed limestone, which lowers the normal coefficient of restitution which in turn acts to prevent rocks bouncing off the bench and onto the road below (Richards *et al*,. 2001). Figure 5-7a & b. shows the difference between a bench without a low normal coefficient of restitution compared with one covered in shingle with a low value. The bench without shingle allows 3% of rocks to reach the road, while the one with shingle on it allows less then 1% (details in Appendix 4).

To further increase the protection a 3 m high rock catch fence can be built on the outside of the bench. Figure 5-7c. shows how the rock catch fence effectively stops all rocks from impacting the road. The only problem is rocks launching off the top of the cutting and bypassing the intermediate bench entirely, however the probability of this is very low. The bench has been designed to be 6 m wide as it will allow machinery to access it to clear accumulating rock.

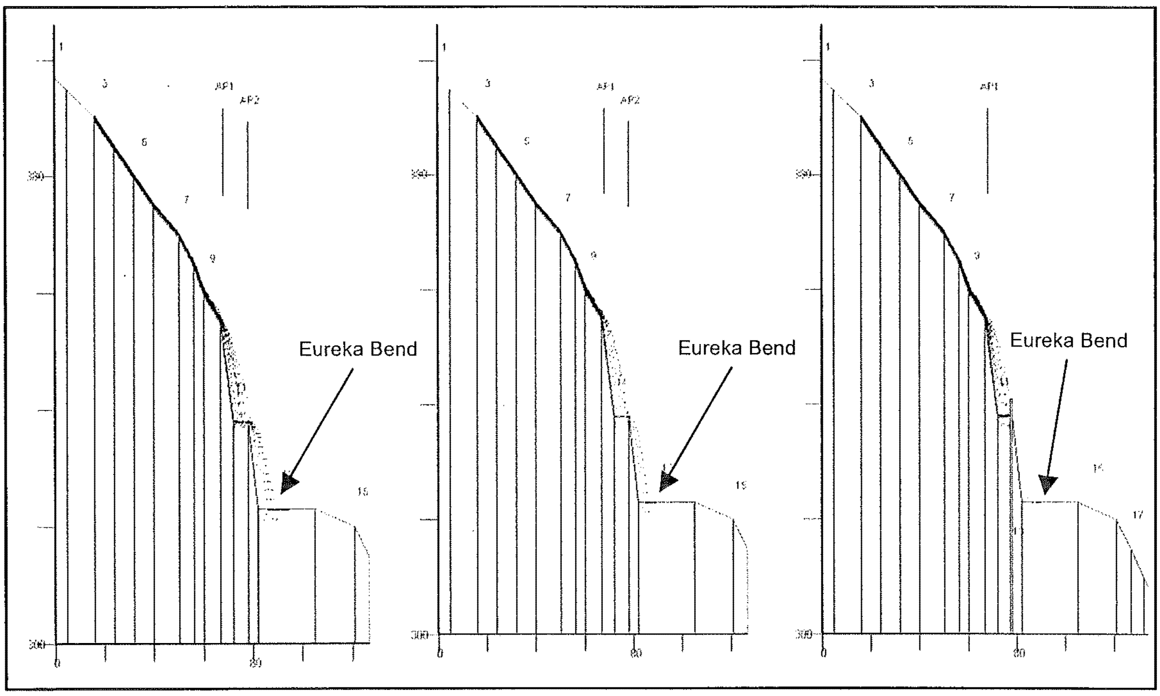


Figure 5-7: Output from CRSP for Design 2.
a. No shingle on bench. b. Shingle placed on intermediate bench. c. Installation of 3 m high rock catch fence (bench has layer of shingle on it).

5.4 Water Control

Drainage or water control measures are one of the most important mitigation techniques that can be used when attempting to stabilise a potentially unstable slope, because they reduce the pore pressure which if left will reduce the effective stress and potentially cause the slope to fail (Terzaghi *et al.,* 1996). Both subsoil and surface drainage techniques can be used to remove the influence of water on slope stability.

For both designs the water control measures would be relatively similar. Both will have subhorizontal drains installed in the face as seepage was recorded during the scanline survey. Surface drainage ditches above the face and toe drains at the base will also be included. Details are as follows:

- Surface drainage – on potentially unstable slopes and during construction projects diversion ditches and intercept drains can be used to intercept surface water and divert it into controlled channels away from the areas at risk. The presence of surface water on the slope can increase the erosion and lead to an increased tendency for small-localised failures (Holtz and Schuster, 1996). Surface water may also infiltrate the head of slope, which could lead to increased pore water pressures within the slope, and a higher risk of slope failure or landslide reactivation (Terzaghi *et al.*, 1996). Figure 5-8 shows how surface interceptor drains can be installed above the face to prevent water infiltrating the slope and toe drains below the slope to stop water infiltrating the road base, as will be used for both Design 1 & 2. For Design 2 there will also be a surface drain installed on the inside of the bench. This will be designed to collect any water from the bench and divert it away thus preventing it from infiltrating the rock mass.

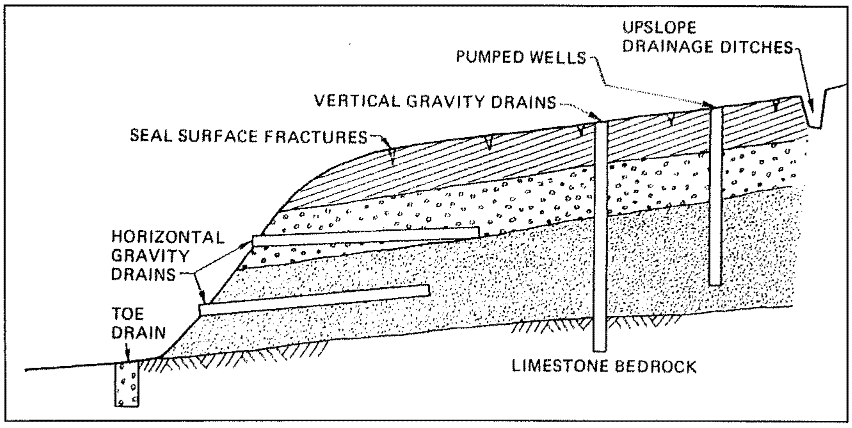


Figure 5-8: Use of surface interceptor drains, subhorizontal drains and toe drains to increase slope stability.
(From Holtz and Schuster, 1996)

- Subhorizontal drains – will be used because seepage was detected in the face. They are a very common technique used for slope stabilisation. They are typically drill holes 120 to 150mm installed at a gradient of 2° to 5° from the horizontal (see Figure 5-8). The holes are then fitted with perforated pipe that allows water to be drawn away from the slope (Holtz and Schuster, 1996). They are a very good means of reducing the volume of water within a face and thus reducing pore water pressures. This is an important consideration in the design of the cut batters due to their height.

5.5 Synthesis

Table 5-1 below summarises the features of both designs, and even though Design 2 creates more excavated material it is the recommended design because it is expected to have better long-term stability than Design 1. The rockfall mitigation measures and drainage will be easier to maintain thus reducing long term maintenance costs.

Table 5-1: Summary of features for Design 1 & 2 proposed for the widening of Eureka Bend.

Design #	Height	Volume Excavated	Long Term Stability	Rockfall Mitigation	Drainage Measures	Advantages	Disadvantages
Design 1	25 m	8000 m^3	Should remain standing at 76° indefinitely.	• Rock catch fence at top of face.	• Surface drain at top of face. • Toe drain at base of batter. • Subhorizontal drain in the face to remove seepage.	• Less material to excavate. • Less expensive • Creates fill for the engineered earth embankment.	• Weathering of cut face may result in small rocks falling onto road. • Large exposed face, open to erosional processes. • Rock catch fence difficult to maintain due to location. • Hard to put in horizontal drain at height.
Design 2	15 m	12 000 m^3	Inclusion of intermediate bench lowers individual batter heights, thus increasing overall stability and access to faces.	• Rock catch fence on the outside of the intermediate bench. • Layer of shingle on bench to control rock bounce.	• Surface drain at top of face. • Toe drain at base of batter. • Surface drain on inside of intermediate bench. • Subhorizontal drain in both faces (above and below intermediate bench) to remove seepage.	• Likely to be more stable long term than Design 1 • More effective rockfall mitigation measures compared to Design 1. • Creates fill for the engineered earth embankment.	• A larger volume of material must be excavated due to the bench. • Greater cost because of this as there may be too much fill for the engineered earth embankment meaning that some will have to be removed from site.

Chapter 6

Summary and Conclusions

6.1 Project Objectives

The primary objective of this project has been to carry out a detailed Engineering Geology assessment of Eureka Bend to identify and evaluate geotechnical considerations in widening of the cut. A secondary objective has been to further assess overall rock mass behaviour in the limestone, and the suitability of excavated materials for use as engineered fill.

6.2 Field Investigations

Various investigations were carried out during the field component of this project to assist in the assessment of the limestone 'block' adjacent to Eureka Bend. These included:

- Thorough site walk over and inspection of relevant outcrops,
- Detailed geological mapping of the zone in question, and,
- A geophysical survey using ground penetrating radar (GPR) to determine continuity of the limestone and the relationship of the 'block' to limestone further to the north.

A review of relevant literature including reports by both GHD and MWH was also conducted to gain a better insight into the processes operating at Eureka Bend. Rock mechanics testing and computer modelling of stability and rockfalls was also carried out back in Christchurch.

6.3 Principal Conclusions

Conclusions regarding the geological and geotechnical setting of Eureka Bend are:

- The steep terrain coupled with the geology of Eureka Bend means that without remediation it will continue to be susceptible to slope failures, including deep-seated failures, shallow landslides, planar failures along bedrock surfaces, rockfalls and slumps within the roading fill. Any ground rupture on the adjacent Pisagh Fault may also create geotechnical concerns.

- The limestone 'block' adjacent to Eureka Bend is not in-situ and has probably rotated into position after a cavity was formed beneath it due to the dissolution of the limestone. Field observations of the 'block' suggest that its dimensions are 60 m × 25 m, with depth presently unknown due to lack of subsurface data.
- The marble on top of the block has probably been deposited by a block slide (or slides) along a planar failure surface. A slab of marble has most likely detached from above the Pisagh Fault zone and slid down to its current location. The appearance of steps in the marble indicates either several blocks or the break up of a single block.
- GPR results suggest that the traverse that was surveyed is likely to be in the in-situ limestone, and not part of the 'block' because of the presence of parallel joints and possible bedding planes seen in the results. The GPR profile shows bedding and jointing in an intact rock mass with little or no dilation.
- Rock strength testing of limestone and marble taken from the face adjacent to Eureka Bend indicated that the rippability of the material would be from 'extremely hard ripping' through to 'blasting required'. The point load results converted to equivalent UCS values indicate that the material would have the required strength for use as fill in an engineered earth embankment.
- Slake durability testing proved that both the limestone and the marble would be suitably durable for use as fill in the engineered earth embankment.
- Kinematic analysis of defects in the current cut face orientation at Eureka Bend yielded results that suggested that it is stable and not prone to planar, wedge or toppling failures. No analysis of proposed alignments could be done because it is not known how penetrative the discontinuities seen at the road are.
- Rockfall modelling suggests that the road at Eureka Bend is susceptible to rockfall hazards originating from the slopes above the proposed cut face. Rockfalls sourced from the cut face itself are considered unlikely given adequate scaling during construction because joints are widely spaced and the limestone has high intact strength.

- Two designs for cut batters were identified. One involved a single 25 m high cut face, while the other included an intermediate bench at a height of 15 m. Design 2 was chosen as the preferred option because the addition of the intermediate bench is likely to provide a more stable cut face for long-term stability. The bench also creates easier access for construction and maintenance, and provides a more competent rockfall mitigation measure..

6.4 Further Work

Further investigations need to be conducted at Eureka Bend to clearly indentify the extent of the limestone 'block'.

- Presently the dense vegetation on prevents accurate assessment. To gain a better understanding of the 'block' dimensions, all vegetation and topsoil will have to be removed so that a detailed assessment can be conducted.

- Two sub-horizontal drill holes ≤50 m long should be completed to establish a better understanding of the lithologies and defect orientations within the 'block'.

- Normal stability analysis procedures should follow the generation of new data from drilling and additional surface investigations.

References

Bowles JE 1996. Foundation Analysis and Design. 5th ed, McGraw-Hill. 1175 p.

Cooper RA 1979. Lower Paleozoic rocks of New Zealand. Journal of the Royal Society of New Zealand 9: 29-84.

Cruden DM, Varnes DJ 1996. Landslide Types and Processes. In: Turner AK, Schuster RL ed. Landslides - Investigation and Mitigation. Washington, D.C., National Academy Press. Pp. 36-75.

Davis JL, Annan AP 1989. Ground-penetrating radar for high resolution mapping of soil and rock stratigraphy. Geophysical Prospecting 37(5): 531-552.

Duffy JD, Haller B 1993. Field Tests of Flexible Rockfall Barriers. International Conference on Transportation Facilities through Difficult Terrain, Aspen, Colorado. Pp. 465-473.

Franklin JA, Pells P, McLachlin D, Greminger M, Kutter H, Broch E, van Heerden WL, Vogler UW, Wijk G, Brook N, Robins PJ 2007a. Suggested Methods for Determining Point Load Strength. In: Ulusay R, Hudson JA ed. The Complete ISRM Suggested Methods for Rock Characterization, Testing and Monitoring: 1974-2006. Ankara, Turkey, International Society for Rock Mechanics Turkish National Group. Pp. 121 - 132.

Franklin JA, Vogler UW, Szlavin J, Edmond JM, Bieniawski ZT 2007b. Suggested Methods for Determining Water Content, Porosity, Density, Absorption, and Related Properties and Swelling and Slake-Durability Index Properties. In: Ulusay R, Hudson JA ed. The Complete ISRM Suggested Methods for Rock Characterization, Testing and Monitoring: 1974-2006. Ankara, Turkey, International Society for Rock Mechanics Turkish National Group. Pp. 83 - 98.

GHD 2008. Report for SH60 Eureka Bend – Geotechnical Assessment Report (Final Draft). *For Transit New Zealand, contract number TNZ 131PT.* GHD New Zealand Limited, Christchurch, New Zealand. 19 p + appendices.

GHD 2007. Report for SH60 Eureka Bend – Identification of Options Report. *For Transit New Zealand, contract number TNZ 131PT.* GHD New Zealand Limited, Christchurch, New Zealand. 48 p + appendices.

Goodman RE 1980. Introduction to Rock Mechanics. 1st ed. New York, John Wiley & Sons. 478 p.

Grindley GW 1980. Sheet S13 – Cobb. Geological Map of New Zealand 1:63 360. Department of Scientific and Industrial Research, Wellington, New Zealand. 1 sheet + 48 p.

Hadley J 1978. Madison Canyon Rockslide, Montana, USA. In: Voight B ed. Rockslides and Avalanches, 1 - Natural Phenomena. New York, Elsevier Scientific Publishing Company. Pp. 167 - 180.

Holtz RD, Schuster RL 1996. Stabilization of Soil Slopes. In: Turner AK, Schuster RL ed. Landslides - Investigation and Mitigation. Washington, D.C., National Academy Press. Pp. 439-473.

Jol HM, Bristow CS 2003. GPR in sediments: advice on data collection, basic processing and interpretation, a good practices guide. In: Bristow CS, Jol HM ed. Ground Penetrating Radar in Sediments. London, Geological Society. Pp. 9-27.

Jongens R 1992. Investigation of an Arthur Marble Brecciated Sheet, Upper Takaka, Northwest Nelson. Unpublished B.Sc. Honours Project, University of Canterbury, Christchurch, New Zealand. 72 p.

Kobayashi Y, Harp EL, Hagawa T 1990. Simulation of rock falls triggered by earthquakes. Rock Mech. Rock Engng 23(1): 1-20.

Leask WL 1980. Basin analysis of Tertiary strata in Golden Bay, Nelson. Unpublished M.Sc. thesis, Victoria University, Wellington, New Zealand.

MWH 2006. Geotechnical Assessment Report for State Highway 60 – Eureka Bend Slump and Underslip RP56/10.91. MWH New Zealand Limited, Nelson, New Zealand. 11 p + appendices.

Naser AA 2004. Effects of testing methods and conditions on the elastic properties of limestone rock. Engineering Geology 74(1-2): 139-156.

Pfeiffer T, Higgins J, Andrew R, Schultz R, Beck R 1995. Colorado Rockfall Simulation Program Version 3.0a User's Manual. Colorado School of Mines. 25 p.

Rattenbury MS, Cooper RA, Johnston MR (compilers) 1998. Geology of the Nelson area. Institute of Geological and Nuclear Sciences 1:250 000 geological map 9. Lower Hutt, New Zealand. 1 sheet + 67 p.

Richards LR, Peng B, Bell DH 2001. Laboratory and Field Evaluation of the Normal Coefficient of Restitution for Rocks. In: Sarka P, Eloranta P ed. ISRM Regional Symposium Eurock 2001. Espoo, Finland. Pp. 149 - 155.

Smith DD, Duffy JD 1990. Field Tests and Evaluation of Rockfall Restraining Nets. Division of Transportation Materials and Research, Engineering Geology Branch, California Department of Transportation, Sacramento.

Smith MR 1999. Stone: building stone, rock fill and armourstone in construction. London, Geological Society of London. 478 p.

Terzaghi K, Peck RB, Mesri G 1996. Soil mechanics in engineering practice. 3rd ed. New York, Wiley. 549 p.

Wyllie DC, Norrish NI 1996. Stabilization of Rock Slopes. In: Turner AK, Schuster RL ed. Landslides - Investigation and Mitigation. Washington, D.C., National Academy Press. Pp. 474-506.

Wyllie DC, Mah CW 2004. Rock Slope Engineering - Civil and Mining. 4th ed. New York, Spon Press. 431 p.

List of Appendices

Appendix 1

MWH Borehole and Test Pit Logs

1. MWH Borehole Logs
2. MWH Test Pit Logs

MWH MWH NZ Ltd	MWH New Zealand Ltd LOG OF CORED BOREHOLE	Job No: Z1057102 Hole No: BH 1 Sheet: 1 of 4
	Client: Transit New Zealand	Started: 12/09/06
	Project: Eureka Bend Landslip	Finished: 13/09/06
Drilling Method: NQ	Location: See Geotechnical Site Plan	Logged: IRW Checked:
SPT blows (*) denotes solid cone	Equipment Type:	RL Surface:
	Borehole Diameter: Inclination: 90 deg Bearing:	Datum:

groundwater	samples/tests	depth (m)	graphic log	USCS symbol	Material Description	Comments notes, structure and additional observations
		0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8			Clayey f.m.c. GRAVEL, light grey, dry, Well rounded gravels. Road base FILL containing typical Takaka river gravels of predominantly greywacke, schist and quartzite clasts.	
		0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4 2.5 2.6 2.7 2.8 2.9 3.0 3.1 3.2 3.3 3.4 3.5		GP-GC	Clayey f.m.c. GRAVEL, with some, boulder: dark brown, wet, FILL containing mixed clasts of limestone and marble.	
		3.6 3.7 3.8 3.9 4.0 4.1 4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9 5.0 5.1 5.2 5.3 5.4 5.5 5.6 5.7		CL	Gravelly CLAY, light greenish brown, wet, medium plasticity, Gravels are subangular to subrounded, fmc. FILL containing Pikikiruna Schist clasts.	

Notes:	Driller:CW Drilling

MWH MWH NZ Ltd	MWH New Zealand Ltd LOG OF CORED BOREHOLE	Job No: Z1057102 Hole No: BH 1 Sheet: 2 of 4
	Client: Transit New Zealand	Started: 12/09/06
	Project: Eureka Bend Landslip	Finished: 13/09/06
Drilling Method: NQ	Location: See Geotechnical Site Plan	Logged: IRW Checked:
SPT blows (*) denotes solid cone	Equipment Type:	RL Surface:
	Borehole Diameter: Inclination: 90 deg Bearing:	Datum:

groundwater	samples/tests	depth (m)	graphic log	USCS symbol	Material Description	Comments notes, structure and additional observations
		5.8		CL		
		5.9 6.0 6.1 6.2 6.3 6.4 6.5 6.6 6.7 6.8 6.9 7.0 7.1 7.2 7.3 7.4 7.5 7.6 7.7 7.8 7.9 8.0 8.1 8.2 8.3		CL-ML	Silty CLAY, with some, f, gravel; yellowish brown, wet	
		8.4 8.5 8.6 8.7 8.8 8.9 9.0 9.1 9.2 9.3 9.4 9.5 9.6 9.7 9.8 9.9 10.0 10.1			Slightly weathered light grey LIMESTONE, strong	Soft, wet clay in contact with Limestone. Contact at 40 degrees to the S. Loss of circulation from 8.3 downwards.
		10.2 10.3 10.4 10.5 10.6 10.7 10.8			Moderately weathered light yellowish brown LIMESTONE, moderately strong	Coarse grained Limestone, massive with some clay at 10.8m. Upper contact with grey (slightly weathered) limestone at 50 degrees.
		10.9 11.0 11.1			VOID	
		11.2 11.3 11.4			Moderately weathered light yellowish brown LIMESTONE, moderately strong	

Notes:	Driller:CW Drilling

MWH

MWH NZ Ltd

MWH New Zealand Ltd LOG OF CORED BOREHOLE		
	Job No:	Z1057102
	Hole No:	BH 1
	Sheet:	3 of 4
Client: Transit New Zealand	Started:	12/09/06
Project: Eureka Bend Landslip	Finished:	13/09/06
Drilling Method: NQ	Location: See Geotechnical Site Plan	Logged: IRW
		Checked:
SPT blows (*) denotes solid cone	Equipment Type:	RL Surface:
	Borehole Diameter: Inclination: 90 deg Bearing:	Datum:

groundwater	samples/tests	depth (m)	graphic log	USCS symbol	Material Description	Comments notes, structure and additional observations
		11.5 – 12.5			Moderately weathered light yellowish brown LIMESTONE, moderately strong *(continued)*	
		12.5 – 12.8			VOID	
		12.8 – 12.9			Moderately weathered light yellowish brown LIMESTONE, moderately strong	
		12.9 – 13.2			VOID	
		13.2 – 13.5			Moderately weathered light yellowish brown LIMESTONE, moderately strong	Lower contact with grey limestone at 30 degrees
		13.5 – 14.0			Slightly weathered light grey LIMESTONE, strong	Lower contact with moderately weathered yellowish brown Limestone at 44 degrees
		14.0 – 14.4			Moderately weathered yellowish brown LIMESTONE, moderately strong	
		14.4 – 15.9			Slightly weathered light grey LIMESTONE, strong	Lower contact with yellowish brown Limestone at 20 degrees
		15.9 – 16.2			Moderately weathered light yellowish brown LIMESTONE, moderately strong	Lower contact with grey Limestone at 30 degrees
		16.2 – 17.1			Slightly weathered light grey LIMESTONE, strong	

Depth scale (m): 11.5, 11.6, 11.7, 11.8, 11.9, 12.0, 12.1, 12.2, 12.3, 12.4, 12.5, 12.6, 12.7, 12.8, 12.9, 13.0, 13.1, 13.2, 13.3, 13.4, 13.5, 13.6, 13.7, 13.8, 13.9, 14.0, 14.1, 14.2, 14.3, 14.4, 14.5, 14.6, 14.7, 14.8, 14.9, 15.0, 15.1, 15.2, 15.3, 15.4, 15.5, 15.6, 15.7, 15.8, 15.9, 16.0, 16.1, 16.2, 16.3, 16.4, 16.5, 16.6, 16.7, 16.8, 16.9, 17.0, 17.1

Notes: | Driller: CW Drilling

MWH

MWH NZ Ltd

MWH New Zealand Ltd LOG OF CORED BOREHOLE		
	Job No:	Z1057102
	Hole No:	BH 1
	Sheet:	4 of 4
Client: Transit New Zealand	Started:	12/09/06
Project: Eureka Bend Landslip	Finished:	13/09/06
Drilling Method: NQ	Location: See Geotechnical Site Plan	Logged: IRW
		Checked:
SPT blows (*) denotes solid cone	Equipment Type:	RL Surface:
	Borehole Diameter: Inclination: 90 deg Bearing:	Datum:

groundwater	samples/tests	depth (m)	graphic log	USCS symbol	Material Description	Comments notes, structure and additional observations
		17.2 – 17.3			Slightly weathered light grey LIMESTONE, strong *(continued)*	
		17.3			Terminated at 17.3 m	

Depth scale (m): 17.2, 17.3, 17.4, 17.5, 17.6, 17.7, 17.8, 17.9, 18.0, 18.1, 18.2, 18.3, 18.4, 18.5, 18.6, 18.7, 18.8, 18.9, 19.0, 19.1, 19.2, 19.3, 19.4, 19.5, 19.6, 19.7, 19.8, 19.9, 20.0, 20.1, 20.2, 20.3, 20.4, 20.5, 20.6, 20.7, 20.8, 20.9, 21.0, 21.1, 21.2, 21.3, 21.4, 21.5, 21.6, 21.7, 21.8, 21.9, 22.0, 22.1, 22.2, 22.3, 22.4, 22.5, 22.6, 22.7, 22.8

Notes: | Driller: CW Drilling

MWH New Zealand Ltd
LOG OF CORED BOREHOLE

MWH
MWH NZ Ltd

Job No:	Z1057102
Hole No:	BH 2
Sheet:	1 of 3
Client:	Transit New Zealand
Project:	Eureka Bend Landslip
Started:	13/09/06
Finished:	14/09/06
Drilling Method:	NQ
Location:	See Geotechnical Site Plan
Logged:	IRW
Checked:	
SPT blows (*) denotes solid cone	
Equipment Type:	
RL Surface:	
Borehole Diameter:	
Inclination:	90 deg
Bearing:	
Datum:	

depth (m): 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4 2.5 2.6 2.7 2.8 2.9 3.0 3.1 3.2 3.3 3.4 3.5 3.6 3.7 3.8 3.9 4.0 4.1 4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9 5.0 5.1 5.2 5.3 5.4 5.5 5.6 5.7

groundwater	samples/tests	USCS symbol	Material Description	Comments (notes, structure and additional observations)
			Clayey f.m.c. GRAVEL, light grey, dry. Well rounded gravels. Road base FILL containing typical Takaka River gravels of predominantly greywacke, schist and quartzite clasts.	
		GP-GC	Clayey f.m.c. GRAVEL, with some, boulder; dark brown, wet, FILL containing mixed clasts of limestone and marble.	
		CL	Gravelly CLAY, light greenish brown, wet, medium plasticity, Gravels are subangular to subrounded, fmc. FILL containing Pikikiruna Schist clasts.	

Notes:

Driller: CW Drilling

MWH New Zealand Ltd
LOG OF CORED BOREHOLE

MWH
MWH NZ Ltd

Job No:	Z1057102
Hole No:	BH 2
Sheet:	2 of 3
Client:	Transit New Zealand
Project:	Eureka Bend Landslip
Started:	13/09/06
Finished:	14/09/06
Drilling Method:	NQ
Location:	See Geotechnical Site Plan
Logged:	IRW
Checked:	
SPT blows (*) denotes solid cone	
Equipment Type:	
RL Surface:	
Borehole Diameter:	
Inclination:	90 deg
Bearing:	
Datum:	

depth (m): 5.8 5.9 6.0 6.1 6.2 6.3 6.4 6.5 6.6 6.7 6.8 6.9 7.0 7.1 7.2 7.3 7.4 7.5 7.6 7.7 7.8 7.9 8.0 8.1 8.2 8.3 8.4 8.5 8.6 8.7 8.8 8.9 9.0 9.1 9.2 9.3 9.4 9.5 9.6 9.7 9.8 9.9 10.0 10.1 10.2 10.3 10.4 10.5 10.6 10.7 10.8 10.9 11.0 11.1 11.2 11.3 11.4

groundwater	samples/tests	USCS symbol	Material Description	Comments (notes, structure and additional observations)
		CL	Gravelly CLAY, light greenish brown, wet, medium plasticity. Gravels are subangular to subrounded, fmc. FILL containing Pikikiruna Schist clasts. *(continued)*	
		CL-ML	Silty CLAY, with some, gravel; greenish brown, wet, medium plasticity	
			Moderately weathered light yellowish brown LIMESTONE, moderately strong	Contact with overlying Silty Clay at 29 degrees to the south. Tight joint at 8.85m dipping at 26 degrees south Loss of circulation at 8.4m downwards.
			VOID	
			Moderately weathered light yellowish brown LIMESTONE, moderately strong	
			Slightly weathered light grey LIMESTONE, strong	Upper contact with yellowish brown Limestone dips at 52 degrees to the south

Notes:

Driller: CW Drilling

MWH

MWH NZ Ltd

MWH New Zealand Ltd
LOG OF CORED BOREHOLE

Job No:	Z1057102
Hole No:	BH 2
Sheet:	3 of 3
Client:	Transit New Zealand
Project:	Eureka Bend Landslip
Started:	13/09/06
Finished:	14/09/06
Drilling Method:	NQ
Location:	See Geotechnical Site Plan
Logged:	IRW
Checked:	
SPT blows (*) denotes solid cone	
Equipment Type:	
RL Surface:	
Borehole Diameter:	Inclination: 90 deg Bearing:
Datum:	

Columns: groundwater | samples/tests | depth (m) | graphic log | USCS symbol | Material Description | Comments (notes, structure and additional observations)

Depth (m): 11.5, 11.6, 11.7, 11.8, 11.9, 12.0, 12.1, 12.2, 12.3, 12.4, 12.5, 12.6, 12.7, 12.8, 12.9, 13.0, 13.1, 13.2, 13.3, 13.4, 13.5, 13.6, 13.7, 13.8, 13.9, 14.0, 14.1, 14.2, 14.3, 14.4, 14.5, 14.6, 14.7, 14.8, 14.9, 15.0, 15.1, 15.2, 15.3, 15.4, 15.5, 15.6, 15.7, 15.8, 15.9, 16.0, 16.1, 16.2, 16.3, 16.4, 16.5, 16.6, 16.7, 16.8, 16.9, 17.0, 17.1

Material Description	Comments
Moderately weathered yellowish brown LIMESTONE, moderately strong	Upper contact with grey Limestone dips at 38 degrees south. Limestone i coarse grained. Completely weathered Limestone from 12.8 to 13.3m
Slightly weathered light grey LIMESTONE, strong	
Moderately weathered light yellowish brown LIMESTONE, moderately strong	
Terminated at 14.3 m	

Notes

Driller:CW Drilling

MWH

MWH NZ Ltd

MWH New Zealand Ltd
LOG OF CORED BOREHOLE

Job No:	Z1057102
Hole No:	BH 3
Sheet:	1 of 3
Client:	Transit New Zealand
Project:	Eureka Bend Landslip
Started:	13/09/06
Finished:	14/09/06
Drilling Method:	NQ
Location:	See Geotechnical Site Plan
Logged:	IRW
Checked:	
SPT blows (*) denotes solid cone	
Equipment Type:	
RL Surface:	
Borehole Diameter:	Inclination: 90 deg Bearing:
Datum:	

Columns: groundwater | samples/tests | depth (m) | graphic log | USCS symbol | Material Description | Comments (notes, structure and additional observations)

Depth (m): 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3.0, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 4.0, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 5.0, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7

Material Description	Comments
Clayey f.m.c. GRAVEL, light grey, dry. Well rounded gravels. Road base FILL containing typical Takaka river gravels of predominantly greywacke, schist and quartzite clasts.	
Clayey f.m.c. GRAVEL, with some cobbles; dark brown, wet. FILL. Upper part of fill containing mixed clasts of limestone and marble. Lower fill containing predominantly Pikikiruna Schist clasts.	
Silty CLAY, with minor, f. gravel; yellowish brown, wet, low plasticity	
Moderately weathered light yellowish brown LIMESTONE, moderately strong	Upper contact of Limestone with Silty Clay dips at 42 degrees to the south. Loss of circulation at 3.6m downwards.

Notes

Driller:CW Drilling

MWH
MWH NZ Ltd

MWH New Zealand Ltd
LOG OF CORED BOREHOLE

Job No:	Z1057102
Hole No:	BH 3
Sheet:	2 of 3
Client:	Transit New Zealand
Project:	Eureka Bend Landslip
Started:	13/09/06
Finished:	14/09/06
Drilling Method:	NQ
Location:	See Geotechnical Site Plan
Logged:	IRW
Checked:	
SPT blows (*) denotes solid cone	
Equipment Type:	
RL Surface:	
Borehole Diameter:	
Inclination:	90 deg
Bearing:	
Datum:	

groundwater	samples/tests	depth (m)	graphic log	USCS symbol	Material Description	Comments notes, structure and additional observations
		5.8 – 7.0			Moderately weathered light yellowish brown LIMESTONE, moderately strong *(continued)*	Upper contact of Limestone with Silty Clay dips at 42 degrees to the south. Loss of circulation at 3.6m downwards.
		7.1			Completely weathered light yellowish brown LIMESTONE, very weak	
		7.3 – 9.4			Moderately weathered light yellowish brown LIMESTONE, moderately strong	
		9.5 – 10.0			Slightly weathered light grey LIMESTONE, strong	Upper contact dips at 52 degrees to the south. Lower contact dips at 60 degrees to the south.
		10.1 – 11.4			Moderately weathered light yellowish brown LIMESTONE, moderately strong	

Depth scale (m): 5.8, 5.9, 6.0, 6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 6.8, 6.9, 7.0, 7.1, 7.2, 7.3, 7.4, 7.5, 7.6, 7.7, 7.8, 7.9, 8.0, 8.1, 8.2, 8.3, 8.4, 8.5, 8.6, 8.7, 8.8, 8.9, 9.0, 9.1, 9.2, 9.3, 9.4, 9.5, 9.6, 9.7, 9.8, 9.9, 10.0, 10.1, 10.2, 10.3, 10.4, 10.5, 10.6, 10.7, 10.8, 10.9, 11.0, 11.1, 11.2, 11.3, 11.4

Notes:

Driller:CW Drilling

MWH
MWH NZ Ltd

MWH New Zealand Ltd
LOG OF CORED BOREHOLE

Job No:	Z1057102
Hole No:	BH 3
Sheet:	3 of 3
Client:	Transit New Zealand
Project:	Eureka Bend Landslip
Started:	13/09/06
Finished:	14/09/06
Drilling Method:	NQ
Location:	See Geotechnical Site Plan
Logged:	IRW
Checked:	
SPT blows (*) denotes solid cone	
Equipment Type:	
RL Surface:	
Borehole Diameter:	
Inclination:	90 deg
Bearing:	
Datum:	

groundwater	samples/tests	depth (m)	graphic log	USCS symbol	Material Description	Comments notes, structure and additional observations
		11.5				
		11.6 – 11.8			VOID	
		11.9 – 13.0			Moderately weathered light yellowish brown LIMESTONE, moderately strong	Limestone highly weathered and weak.
		13.1 – 14.0			VOID	
		14.1 – 14.4			Moderately weathered light yellowish brown LIMESTONE, moderately strong	
		14.5			Terminated at 14.4 m	

Depth scale (m): 11.5, 11.6, 11.7, 11.8, 11.9, 12.0, 12.1, 12.2, 12.3, 12.4, 12.5, 12.6, 12.7, 12.8, 12.9, 13.0, 13.1, 13.2, 13.3, 13.4, 13.5, 13.6, 13.7, 13.8, 13.9, 14.0, 14.1, 14.2, 14.3, 14.4, 14.5, 14.6, 14.7, 14.8, 14.9, 15.0, 15.1, 15.2, 15.3, 15.4, 15.5, 15.6, 15.7, 15.8, 15.9, 16.0, 16.1, 16.2, 16.3, 16.4, 16.5, 16.6, 16.7, 16.8, 16.9, 17.0, 17.1

Notes:

Driller:CW Drilling

LOG OF CORED BOREHOLE EUREKA BEND.GPJ MWH NZ.GDT 9/7/08

MWH NZ Ltd	MWH New Zealand Ltd LOG OF TEST PIT	Job No: Z1057102
		Hole No: TP 1
		Sheet: 1 of 2
	Client: Transit New Zealand	Started: 13/09/06
	Project: Eureka Bend Landslip	Finished: 13/09/06
Investigation Method:	Location: See Geotechnical Site Plan	Logged: IRW
		Checked:
	Equipment Type: 20 tonne Excavator	RL Surface:
	Bucket width:	Datum:

groundwater	shear vane (kPa) (peak/residual)	samples/tests	depth (m)	graphic log	USCS symbol	Material Description	consistency/RD	moisture condition	comments (notes, structure, and additional observations)	Scala Penetration (blows/100mm)
			0.0–0.3			TOPSOIL, black, moist, Contains organics				
			0.3–3.8		CL-ML	Silty CLAY, yellowish green, moist, low plasticity				

NZMS Map and grid reference | Notes: | Contractor:

TEST PIT LOG EUREKA BEND.GPJ MWH NZ.GDT 9/7/08

71

MWH NZ Ltd	MWH New Zealand Ltd LOG OF TEST PIT	Job No: Z1057102
		Hole No: TP 1
		Sheet: 2 of 2
	Client: Transit New Zealand	Started: 13/09/06
	Project: Eureka Bend Landslip	Finished: 13/09/06
Investigation Method:	Location: See Geotechnical Site Plan	Logged: IRW
		Checked:
	Equipment Type: 20 tonne Excavator	RL Surface:
	Bucket width:	Datum:

groundwater	shear vane (kPa) (peak/residual)	samples/tests	depth (m)	graphic log	USCS symbol	Material Description	consistency/RD	moisture condition	comments (notes, structure, and additional observations)	Scala Penetration (blows/100mm)
			3.8–4.1		CL-ML	Silty CLAY, yellowish green, moist, low plasticity *(continued)*				
			4.1			Limestone exposed on the upslope face from surface to 4.10m. Limestone exposed on the floor of pit. Terminated at 4.1 m				

NZMS Map and grid reference | Notes: | Contractor:

TEST PIT LOG EUREKA BEND.GPJ MWH NZ.GDT 9/7/08

MWH
MWH NZ Ltd

MWH New Zealand Ltd
LOG OF TEST PIT

Job No:	Z1057102
Hole No:	TP 2
Sheet:	1 of 1
Client: Transit New Zealand	Started: 13/09/06
Project: Eureka Bend Landslip	Finished: 13/09/06
Investigation Method:	
Location: See Geotechnical Site Plan	Logged: IRW
	Checked:
Equipment Type: 20 tonne Excavator	RL Surface:
Bucket width:	Datum:

depth (m)	USCS symbol	Material Description
0.0–0.2		TOPSOIL, black, moist. Contains organics
0.2–2.8	CL-ML	Silty CLAY, yellowish brown, moist, low plasticity
2.8–2.9	CL-ML	Silty CLAY, dark greenish brown, wet, low plasticity
2.9–3.0		Limestone exposed at base of pit. Contact with overlying Silty Clay dips at 44 degrees to the south.
3.0		Terminated at 3 m

Columns: groundwater; shear vane (kPa) (peak/residual); samples/tests; depth (m); graphic log; USCS symbol; Material Description; consistency/RD; moisture condition; comments (notes, structure, and additional observations); Scala Penetration (blows/100mm) 0 2 4 6 8 10 12 14

NZMS Map and grid reference | Notes: | Contractor:

TEST PIT LOG EUREKA BEND.GPJ MWH NZ.GDT 9/7/08

MWH
MWH NZ Ltd

MWH New Zealand Ltd
LOG OF TEST PIT

Job No:	Z1057102
Hole No:	TP 3
Sheet:	1 of 1
Client: Transit New Zealand	Started: 13/09/06
Project: Eureka Bend Landslip	Finished: 13/09/06
Investigation Method:	
Location: See Geotechnical Site Plan	Logged: IRW
	Checked:
Equipment Type: 20 tonne Excavator	RL Surface:
Bucket width:	Datum:

depth (m)	USCS symbol	Material Description
0.0–0.1		Black, moist. Contains organics
0.1–1.4	CL-ML	Silty CLAY, yellowish brown, moist, low plasticity
1.4–1.5	CL-ML	Silty CLAY, dark greenish brown, wet, low plasticity
1.5–1.6		Limestone exposed at base of cliff. Contact dips at 40 degrees to the south.
1.6		Terminated at 1.6 m

Columns: groundwater; shear vane (kPa) (peak/residual); samples/tests; depth (m); graphic log; USCS symbol; Material Description; consistency/RD; moisture condition; comments (notes, structure, and additional observations); Scala Penetration (blows/100mm) 0 2 4 6 8 10 12 14

NZMS Map and grid reference | Notes: | Contractor:

TEST PIT LOG EUREKA BEND.GPJ MWH NZ.GDT 9/7/08

MWH New Zealand Ltd — LOG OF TEST PIT

MWH — MWH NZ Ltd

Job No:	Z1057102
Hole No:	TP 4
Sheet:	1 of 1
Client:	Transit New Zealand
Project:	Eureka Bend Landslip
Started:	13/09/06
Finished:	13/09/06
Investigation Method:	
Location:	See Geotechnical Site Plan
Logged:	IRW
Checked:	
Equipment Type:	20 tonne Excavator
RL Surface:	
Bucket width:	
Datum:	

groundwater	shear vane (kPa) (peak/residual)	samples/tests	depth (m)	graphic log	USCS symbol	Material Description	consistency/RD	moisture condition	comments (notes, structure, and additional observations)	Scala Penetration (blows/100mm) 0 2 4 6 8 10 12 14
			0.0–0.1			Black, moist. Contains organics				
			0.1–3.1		CL-ML	Silty CLAY, yellowish brown, moist, low plasticity				
			3.1–3.2			Limestone exposed at bottom of pit. Contact dips at 58 degrees to the south.				
			3.2			Terminated at 3.2 m				

NZMS Map and grid reference | Notes: | Contractor:

TEST PIT LOG EUREKA BEND.GPJ MWH NZ.GDT 9/7/08

MWH New Zealand Ltd — LOG OF TEST PIT

MWH — MWH NZ Ltd

Job No:	Z1057102
Hole No:	TP 5
Sheet:	1 of 2
Client:	Transit New Zealand
Project:	Eureka Bend Landslip
Started:	28/09/06
Finished:	28/09/06
Investigation Method:	
Location:	See Geotechnical Site Plan
Logged:	IRW
Checked:	
Equipment Type:	20 tonne Excavator
RL Surface:	
Bucket width:	
Datum:	

groundwater	shear vane (kPa) (peak/residual)	samples/tests	depth (m)	graphic log	USCS symbol	Material Description	consistency/RD	moisture condition	comments (notes, structure, and additional observations)	Scala Penetration (blows/100mm) 0 2 4 6 8 10 12 14
			0.0–0.05			Asphalt				
			0.05–1.1			Sandy f.m.c. GRAVEL, with some, silt; and, clay; yellowish brown, grey, moist. The top 0.2m of fill is dense while the underlying fill is loose and consists of river gravels.				
			1.1–3.8		CL-ML	Silty CLAY, yellowish brown, moist, low plasticity				

NZMS Map and grid reference | Notes: | Contractor:

TEST PIT LOG EUREKA BEND.GPJ MWH NZ.GDT 9/7/08

MWH

MWH NZ Ltd

MWH New Zealand Ltd

LOG OF TEST PIT

Job No:	Z1057102
Hole No:	TP 5
Sheet:	2 of 2
Client:	Transit New Zealand
Project:	Eureka Bend Landslip
Started:	28/09/06
Finished:	28/09/06
Investigation Method:	
Location:	See Geotechnical Site Plan
Logged:	IRW
Checked:	
Equipment Type:	20 tonne Excavator
RL Surface:	
Bucket width:	
Datum:	

groundwater	shear vane (kPa) (peak/residual)	samples/tests	depth (m)	graphic log	USCS symbol	Material Description	consistency/RD	moisture condition	comments (notes, structure, and additional observations)	Scala Penetration (blows/100mm) 0 2 4 6 8 10 12 14
			3.9 – 4.0		CL-ML	Silty CLAY, yellowish brown, moist, low plasticity *(continued)*				
			4.0 – 4.1			Slightly weathered whitish yellow LIMESTONE, strong				
			4.1			Terminated at 4.1 m				

Depth scale: 3.9, 4.0, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 5.0, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 6.0, 6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 6.8, 6.9, 7.0, 7.1, 7.2, 7.3, 7.4, 7.5, 7.6

NZMS Map and grid reference | Notes: | Contractor:

TEST PIT LOG EUREKA BEND.GPJ MWH NZ.GDT 9/7/08

MWH

MWH NZ Ltd

MWH New Zealand Ltd

LOG OF TEST PIT

Job No:	Z1057102
Hole No:	TP 6
Sheet:	1 of 1
Client:	Transit New Zealand
Project:	Eureka Bend Landslip
Started:	28/09/06
Finished:	28/09/06
Investigation Method:	
Location:	See Geotechnical Site Plan
Logged:	IRW
Checked:	
Equipment Type:	20 tonne Excavator
RL Surface:	
Bucket width:	
Datum:	

groundwater	shear vane (kPa) (peak/residual)	samples/tests	depth (m)	graphic log	USCS symbol	Material Description	consistency/RD	moisture condition	comments (notes, structure, and additional observations)	Scala Penetration (blows/100mm) 0 2 4 6 8 10 12 14
			0.0 – 0.4			Sandy f.m.c. GRAVEL, with some, silt; and, clay; greyish brown, moist				
			0.4 – 0.5			Slightly weathered yellowish white LIMESTONE, strong				
			0.5			Terminated at 0.5 m				

Depth scale: 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3.0, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8

NZMS Map and grid reference | Notes: | Contractor:

TEST PIT LOG EUREKA BEND.GPJ MWH NZ.GDT 9/7/08

MWH
MWH NZ Ltd

MWH New Zealand Ltd
LOG OF TEST PIT

Job No:	Z1057102
Hole No:	TP 7
Sheet:	1 of 1
Client:	Transit New Zealand
Project:	Eureka Bend Landslip
Started:	28/09/06
Finished:	28/09/06
Investigation Method:	
Location:	See Geotechnical Site Plan
Logged:	IRW
Checked:	
Equipment Type:	20 tonne Excavator
RL Surface:	
Bucket width:	
Datum:	

groundwater	shear vane (kPa) (peak/residual)	samples/tests	depth (m)	graphic log	USCS symbol	Material Description	consistency/RD	moisture condition	comments (notes, structure, and additional observations)	Scala Penetration (blows/100mm)
			0.0–0.8			Sandy f.m.c. GRAVEL, with some, silt; and, clay; brown, grey, moist. A layer of placed fine sand at 1.20m below lower drain pipe.				
			0.8–1.7		CL-ML	Silty CLAY, yellowish brown, moist, low plasticity				
			1.7–1.8			Highly weathered yellowish white LIMESTONE, weak				
			1.8			Terminated at 1.8 m				

NZMS Map and grid reference

Notes:

Contractor:

TEST PIT LOG EUREKA BEND.GPJ MWH NZ.GDT 9/7/09

MWH
MWH NZ Ltd

MWH New Zealand Ltd
LOG OF TEST PIT

Job No:	Z1057102
Hole No:	TP 8
Sheet:	1 of 1
Client:	Transit New Zealand
Project:	Eureka Bend Landslip
Started:	28/09/06
Finished:	28/09/06
Investigation Method:	
Location:	See Geotechnical Site Plan
Logged:	IRW
Checked:	
Equipment Type:	20 tonne Excavator
RL Surface:	
Bucket width:	
Datum:	

groundwater	shear vane (kPa) (peak/residual)	samples/tests	depth (m)	graphic log	USCS symbol	Material Description	consistency/RD	moisture condition	comments (notes, structure, and additional observations)	Scala Penetration (blows/100mm)
			0.0–0.4			Sandy f.m.c. GRAVEL, with some, silt; and, clay; grey, brown, moist				
			0.4–1.1		CL-ML	Silty CLAY, yellowish brown, moist, low plasticity				
			1.1–1.2			Slightly weathered yellowish white LIMESTONE, strong				
			1.2			Terminated at 1.2 m				

NZMS Map and grid reference

Notes:

Contractor:

TEST PIT LOG EUREKA BEND.GPJ MWH NZ.GDT 9/7/09

MWH — MWH NZ Ltd

MWH New Zealand Ltd — LOG OF TEST PIT

Job No:	Z1057102
Hole No:	TP 9
Sheet:	1 of 1
Client:	Transit New Zealand
Started:	28/09/06
Project:	Eureka Bend Landslip
Finished:	28/09/06
Investigation Method:	
Location:	See Geotechnical Site Plan
Logged:	IRW
Checked:	
Equipment Type:	20 tonne Excavator
RL Surface:	
Bucket width:	
Datum:	

groundwater	shear vane (kPa) (peak/residual)	samples/tests	depth (m)	USCS symbol	Material Description	consistency/RD	moisture condition	comments (notes, structure, and additional observations)	Scala Penetration (blows/100mm)
			0.0–0.4		Silty GRAVEL, with some clay; grey, brown, moist				
			0.4–2.5	CL-ML	Silty CLAY, yellowish brown, moist, low plasticity				
			2.5–2.6		Slightly weathered yellowish white LIMESTONE, strong				
			2.6		Terminated at 2.6 m				

NZMS Map and grid reference: | Notes: | Contractor:

MWH — MWH NZ Ltd

MWH New Zealand Ltd — LOG OF TEST PIT

Job No:	Z1057102
Hole No:	TP 10
Sheet:	1 of 1
Client:	Transit New Zealand
Started:	28/09/06
Project:	Eureka Bend Landslip
Finished:	28/09/06
Investigation Method:	
Location:	See Geotechnical Site Plan
Logged:	IRW
Checked:	
Equipment Type:	20 tonne Excavator
RL Surface:	
Bucket width:	
Datum:	

groundwater	shear vane (kPa) (peak/residual)	samples/tests	depth (m)	USCS symbol	Material Description	consistency/RD	moisture condition	comments (notes, structure, and additional observations)	Scala Penetration (blows/100mm)
			0.0–0.4		Silty f.m.c. GRAVEL, with some clay; grey, brown, moist				
			0.4–2.4	CL-ML	Silty CLAY, yellowish brown, moist, low plasticity				
			2.4–2.5		Slightly weathered yellowish white LIMESTONE, strong				
			2.5		Terminated at 2.5 m				

NZMS Map and grid reference: | Notes: | Contractor:

MWH MWH NZ Ltd	MWH New Zealand Ltd LOG OF TEST PIT	Job No: Z1057102
		Hole No: TP 11
		Sheet: 1 of 1
	Client: Transit New Zealand	Started: 28/09/06
	Project: Eureka Bend Landslip	Finished: 28/09/06
Investigation Method:	Location: See Geotechnical Site Plan	Logged: IRW
		Checked:
	Equipment Type: 20 tonne Excavator	RL Surface:
	Bucket width:	Datum:

groundwater	shear vane (kPa) (peak/residual)	samples/tests	depth (m)	graphic log	USCS symbol	Material Description	consistency/RD	moisture condition	comments (notes, structure, and additional observations)	Scala Penetration (blows/100mm) 0 2 4 6 8 10 12 14
			0.0–0.3			TOPSOIL, black, moist				
			0.3–1.8			Gravelly SILT, with minor, clay; dark yellowish brown, moist, low plasticity. Fill cast over from the road.				
			1.8–3.5		CL-ML	Silty CLAY, yellowish brown, moist, low plasticity				
			3.5			Terminated at 3.5 m				

NZMS Map and grid reference	Notes:	Contractor:

TEST PIT LOG EUREKA BEND.GPJ MWH NZ.GDT 9/7/08

Appendix 2

GHD Borehole and Test Pit Logs

1. GHD Borehole Logs
2. GHD Test Pit Logs

GHD

PROJECT: **SH60 Eureka Bend. TNZ131PT**
CLIENT: **Transit New Zealand**
LOCATION: **Eureka Bend, Takaka Hill**
JOB No.: **5125338**
LOGGED BY: **AM**
CHECKED BY: **PF**
COMMENCED: **11/9/07**
COMPLETED: **13/9/07**

Borehole No.: BH101

Page: **1 of 5**

CONTRACTOR: **CW Drilling**
EQUIPMENT: **Rotary Cored**
INCLINATION (deg):
DIAMETER (mm): **61**
X-COORDINATE:
Y-COORDINATE:
R.L. SURFACE (m):
TOTAL DEPTH (m): **24.0m**

Depth (m)	Geological Group	DESCRIPTION OF CORE Rock: (name, weathering, relative strength, colour, cement, defect type, lithological features, bedding, foliation, etc) Soil Description: (minor MAJOR subordinate, consistenct, moisture, plasticity/relative density, grading, etc)	SPT Blow Count ('N' Value)	Core Recovery (%)	RQD (%)	Graphic Log	DEFECT DESCRIPTION (defect type, attitude, spacing, continuity, roughness, infilling etc)	Piezometer Details and Water Levels	Water Loss (%)	Drilling Method
0							Ground Surface			
0	FILL	Medium to coarse GRAVEL (Driller's description)								HQ Triple Tube
1		No recovery	4//1/1/3/4 (8)							
			1//1/3/4 (8)							
2	RECALCIFIED COLLUVIUM?	Clayey GRAVEL, COBBLES and BOULDERS. Orange brown, medium dense to dense, moist. Subrounded, maximum 400mm diameter, moderately weathered bioclastic limestone, weak; clay is highly plastic.					2.45m: Joint, subvertical			
		VOID	25//25 (25)							
3		Clayey GRAVEL, COBBLES and BOULDERS. Orange brown, medium dense to dense, moist. Subrounded, maximum 400mm diameter, moderately weathered bioclastic limestone, weak; clay is highly plastic.	18//21/18/16 for 225mm (45)				3.9m: Joint, planar, rough, 45°, iron stained	20mm upvc pipe		
4		VOID								
5										

Core Boxes 6 Comments Cased to 1.3m.
Shear Vane
Factor (as per NZGS Guideline)
Core will be stored for 1 month unless alternative arrangements are made

GHD

PROJECT: **SH60 Eureka Bend. TNZ131PT**
CLIENT: **Transit New Zealand**
LOCATION: **Eureka Bend, Takaka Hill**
JOB No.: **5125338**
LOGGED BY: **AM**
CHECKED BY: **PF**
COMMENCED: **11/9/07**
COMPLETED: **13/9/07**

Borehole No.: BH101

Page: **2 of 5**

CONTRACTOR: **CW Drilling**
EQUIPMENT: **Rotary Cored**
INCLINATION (deg):
DIAMETER (mm): **61**
X-COORDINATE:
Y-COORDINATE:
R.L. SURFACE (m):
TOTAL DEPTH (m): **24.0m**

Depth (m)	Geological Group	DESCRIPTION OF CORE Rock: (name, weathering, relative strength, colour, cement, defect type, lithological features, bedding, foliation, etc) Soil Description: (minor MAJOR subordinate, consistenct, moisture, plasticity/relative density, grading, etc)	SPT Blow Count ('N' Value)	Core Recovery (%)	RQD (%)	Graphic Log	DEFECT DESCRIPTION (defect type, attitude, spacing, continuity, roughness, infilling etc)	Piezometer Details and Water Levels	Water Loss (%)	Drilling Method
5	RECALCIFIED COLLUVIUM?	Moderately weathered light brownish grey bioclastic limestone; weak to moderately strong.	5//3/1/1 (5)				5.2-5.6m: Non-intact 5.75m: Joint, subhorizontal, iron stained			HQ Triple Tube
6			25//7/1/1 (9)				6.6m: Joint, 45°, iron stained 6.7m: Joint, subvertical, iron stained 7.0m: Joint, subhorizontal.			
7		VOID								
8		Moderately weathered light brownish grey bioclastic limestone; moderatley strong.	25//18/7 (25)				8.2-8.6m: Non-intact 8.8-9.1m: Non-intact			
9		VOID								
		Moderately weathered light brownish grey bioclastic limestone; moderately strong								
10										

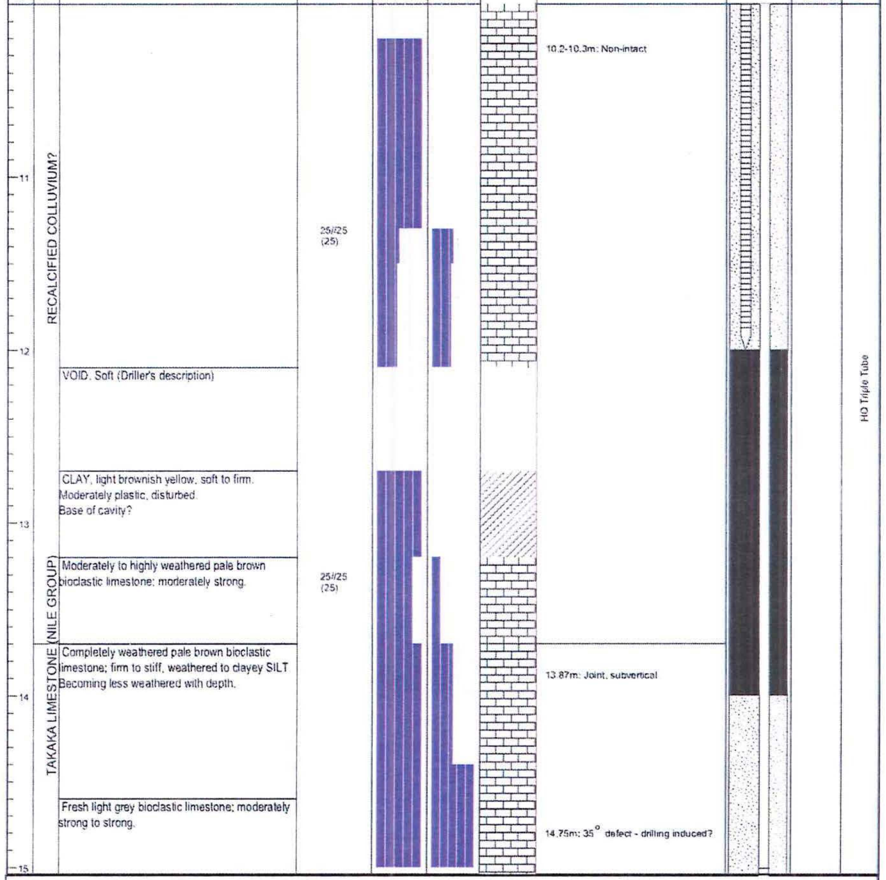
Core Boxes 6 Comments Cased to 1.3m.
Shear Vane
Factor (as per NZGS Guideline)
Core will be stored for 1 month unless alternative arrangements are made

PROJECT: **SH60 Eureka Bend. TNZ131PT**
CLIENT: **Transit New Zealand**
LOCATION: **Eureka Bend, Takaka Hill**
JOB No.: **5125338**
LOGGED BY: **AM**
CHECKED BY: **PF**
COMMENCED: **11/9/07**
COMPLETED: **13/9/07**

Borehole No.: BH101

CONTRACTOR: **CW Drilling**
EQUIPMENT: **Rotary Cored**
INCLINATION (deg):
DIAMETER (mm): **61**
X-COORDINATE:
Y-COORDINATE:
R.L. SURFACE (m):
TOTAL DEPTH (m): **24.0m**

Depth (m)	Geological Group	DESCRIPTION OF CORE Rock: (name, weathering, relative strength, colour, cement, defect type, lithological features, bedding, foliation, etc) Soil Description: (minor MAJOR subordinate, consistenct, moisture, plasticity/relative density, grading, etc)	SPT Blow Count ('N' Value)	Core Recovery (%)	RQD (%)	Graphic Log	DEFECT DESCRIPTION (defect type, attitude, spacing, continuity, roughness, infilling etc)	Piezometer Details and Water Levels	Water Loss (%)	Drilling Method



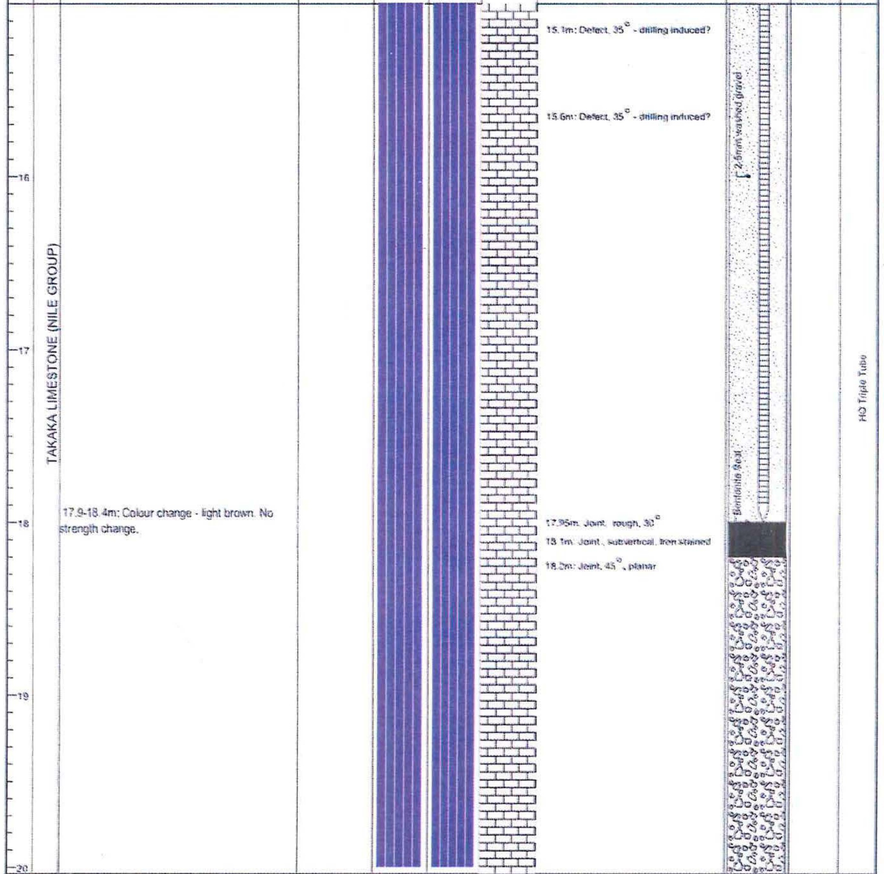
Core Boxes 6
Comments Cased to 1.3m.
Shear Vane
Factor (as per NZGS Guideline)
Core will be stored for 1 month unless alternative arrangements are made

PROJECT: **SH60 Eureka Bend. TNZ131PT**
CLIENT: **Transit New Zealand**
LOCATION: **Eureka Bend, Takaka Hill**
JOB No.: **5125338**
LOGGED BY: **AM**
CHECKED BY: **PF**
COMMENCED: **11/9/07**
COMPLETED: **13/9/07**

Borehole No.: BH101

CONTRACTOR: **CW Drilling**
EQUIPMENT: **Rotary Cored**
INCLINATION (deg):
DIAMETER (mm): **61**
X-COORDINATE:
Y-COORDINATE:
R.L. SURFACE (m):
TOTAL DEPTH (m): **24.0m**

Depth (m)	Geological Group	DESCRIPTION OF CORE Rock: (name, weathering, relative strength, colour, cement, defect type, lithological features, bedding, foliation, etc) Soil Description: (minor MAJOR subordinate, consistenct, moisture, plasticity/relative density, grading, etc)	SPT Blow Count ('N' Value)	Core Recovery (%)	RQD (%)	Graphic Log	DEFECT DESCRIPTION (defect type, attitude, spacing, continuity, roughness, infilling etc)	Piezometer Details and Water Levels	Water Loss (%)	Drilling Method



Core Boxes 6
Comments Cased to 1.3m.
Shear Vane
Factor (as per NZGS Guideline)
Core will be stored for 1 month unless alternative arrangements are made

Borehole No.: BH101

Page: 5 of 5

PROJECT: **SH60 Eureka Bend. TNZ131PT**
CLIENT: **Transit New Zealand**
LOCATION: **Eureka Bend, Takaka Hill**
JOB No.: **5125338**
LOGGED BY: **AM**
CHECKED BY: **PF**
COMMENCED: **11/9/07**
COMPLETED: **13/9/07**

CONTRACTOR: **CW Drilling**
EQUIPMENT: **Rotary Cored**
INCLINATION (deg):
X-COORDINATE:
R.L. SURFACE (m):

DIAMETER (mm): **61**
Y-COORDINATE:
TOTAL DEPTH (m): **24.0m**

Depth (m)	Geological Group	DESCRIPTION OF CORE Rock: (name, weathering, relative strength, colour, cement, defect type, lithological features, bedding, foliation, etc) Soil Description: (minor MAJOR subordinate, consistenct, moisture, plasticity/relative density, grading, etc)	SPT Blow Count ('N' Value)	Core Recovery (%)	RQD (%)	Graphic Log	DEFECT DESCRIPTION (defect type, attitude, spacing, continuity, roughness, infilling etc)	Piezometer Details and Water Levels	Water Loss (%)	Drilling Method
21	TAKAKA LIMESTONE (NILE GROUP)						21.4m: Joint, subhorizontal			HQ Triple Tube
							21.65m: Joint, planar, rough, 45°			
22							22.6m: Joint, planar, 70°			
23										
24							End of Borehole at 24.0m, target depth			
25										

Core Boxes 6
Comments Cased to 1.3m.
Shear Vane
Factor (as per NZGS Guideline)
Core will be stored for 1 month unless alternative arrangements are made

Testpit No.: TP101

Page: 1 of 3

LOG OF TESTPIT

CLIENT: **Transit New Zealand**
PROJECT: **SH60 Eureka Bend**
LOCATION: **Eureka Bend**
JOB No.: **5125338**
LOGGED BY: **ARM**
CHECKED BY:
COMMENCED: **5/10/07**
COMPLETED: **5/10/07**

CONTRACTOR: **SOLLY**
EQUIPMENT: **Hitachi EX20**
X-COORDINATE:
R.L. SURFACE (m):

Y-COORDINATE:
TOTAL DEPTH (m): **2.2m**

Depth (m)	Geological Formation	GEOLOGICAL DESCRIPTION (weathering, relative strength, colour, name, defect type, lithological features, bedding, foliation, mineralogy, cement etc)	Graphic Log	MATERIAL DESCRIPTION (colour, classification, strength, water content, plasticity, grading, etc)	Piezometer Details and Water Levels	DCP blows per 100mm (0 5 15 25)	Shear Vane (kPa)	Depth (m)
				Ground Surface				
0				Road Seal (edge of seal).				0
		FILL		Gravelly SAND with minor silt, light bluish grey, loosely packed, slightly moist. Sand, fine to medium; gravel, coarse, angular to subangular dark grey siltstone (roadstone).				
				Gravelly SAND, greyish brown, loosely packed, slightly moist. Sand, coarse; gravel, fine to medium, subrounded to subangular schist and siltstone (roadstone).				
				Gravelly SAND, brownish orange, loosely packed, slightly moist. Sand, fine, micaceous (weathered schist?); gravel, coarse subangular schist and trace siltstone (roadstone).				
				Sandy GRAVEL with trace clay, light brownish grey, loosely packed, slightly moist. Gravel, fine to coarse and cobble sized, rounded river gravels of various origins and angular schist; sand, medium; clay, locally absent.				
				SAND with some gravel and minor silt, light brownish orange. Loosely packed, slightly moist. Sand, fine; gravel, medium to coarse rounded siltstone (alluvial origin).				
		FILL		Sandy CLAY, with some gravel, and trace silt, brownish orange, moist. Clay, moderately plastic. Sand, fine; gravel, fine to medium rounded river gravel (various origins), angular limestone. Some roadstone and one coal fragments. Sand and gravel proportions locally variable.				
1								1

Shear Vane
Factor (as per NZGS Guideline)
Comments : **TP 1200mm (width) x 3000mm (length). TP remained dry & stable throughout**

CLIENT: Transit New Zealand
PROJECT: SH60 Eureka Bend
LOCATION: Eureka Bend
JOB No.: 5125338
LOGGED BY: ARM
CHECKED BY:
COMMENCED: 5/10/07
COMPLETED: 5/10/07

Testpit No.: TP101

Page: 2 of 3

CONTRACTOR: SOLLY
EQUIPMENT: Hitachi EX20
X-COORDINATE:
R.L. SURFACE (m):
Y-COORDINATE:
TOTAL DEPTH (m): 2.2m

LOG OF TESTPIT

Depth (m)	Geological Formation	GEOLOGICAL DESCRIPTION (weathering, relative strength, colour, name, defect type, lithological features, bedding, foliation, mineralogy, cement etc)	Graphic Log	END OF TESTPIT (2.2m) Unable to Excavate (Boulder) plasticity, grading, etc)	Piezometer Details and Water Levels	DCP blows per 100mm 0 5 15 25	Shear Vane (kPa)	Depth (m)
		FILL		Sandy CLAY continued				
				From 1.4m, with slightly weathered, rounded to subrounded bioclastic limestone boulders, maximum 400mm diameter				
2								2

Shear Vane Factor (as per NZGS Guideline)

Comments : TP 1200mm (width) x 3000mm (length). TP remained dry & stable throughout

CLIENT: Transit New Zealand
PROJECT: SH60 Eureka Bend
LOCATION: Eureka Bend
JOB No.: 5125338
LOGGED BY: ARM
CHECKED BY:
COMMENCED: 5/10/07
COMPLETED: 5/10/07

Testpit No.: TP101

Page: 3 of 3

CONTRACTOR: SOLLY
EQUIPMENT: Hitachi EX20
X-COORDINATE:
R.L. SURFACE (m):
Y-COORDINATE:
TOTAL DEPTH (m): 2.2m

LOG OF TESTPIT

Depth (m)	Geological Formation	GEOLOGICAL DESCRIPTION (weathering, relative strength, colour, name, defect type, lithological features, bedding, foliation, mineralogy, cement etc)	Graphic Log	MATERIAL DESCRIPTION (colour, classification, strength, water content, plasticity, grading, etc)	Piezometer Details and Water Levels	DCP blows per 100mm 0 5 15 25	Shear Vane (kPa)	Depth (m)
		FILL		Sandy CLAY continued				
				END OF TESTPIT (2.2m) Unable to Excavate (Boulder)				
3								3

Shear Vane Factor (as per NZGS Guideline)

Comments : TP 1200mm (width) x 3000mm (length). TP remained dry & stable throughout

CLIENT: **Transit New Zealand**
PROJECT: **SH60 Eureka Bend**
LOCATION: **Eureka Bend**
JOB No.: **5125338**
LOGGED BY: **ARM**
CHECKED BY:
COMMENCED: **5/10/07**
COMPLETED: **5/10/07**

Testpit No.: TP102

Page: 1 of 4

CONTRACTOR: **SOLLY**
EQUIPMENT: **Hitachi EX20**
X-COORDINATE:
Y-COORDINATE:
R.L. SURFACE (m):
TOTAL DEPTH (m): **4.0m**

LOG OF TESTPIT

Depth (m)	Geological Formation	GEOLOGICAL DESCRIPTION (weathering, relative strength, colour, name, defect type, lithological features, bedding, foliation, mineralogy, cement etc)	Graphic Log	MATERIAL DESCRIPTION (colour, classification, strength, water content, plasticity, grading, etc)	Piezometer Details and Water Levels	DCP blows per 100mm (0 5 15 25)	Shear Vane (kPa)	Depth (m)
0				Ground Surface				0
		FILL		Road Seal (edge of seal)				
				Gravelly SAND with minor silt, medium grey, loosely packed, slightly moist. Sand, fine to medium; Gravel, coarse, angular to subangular dark grey siltstone (roadstone).				
				Gravelly SAND, greyish brown, loosely packed, slightly moist. Sand, coarse; gravel, fine to medium, subrounded to subangular schist and siltstone (roadstone).				
				Gravelly SAND, pale yellowish grey, loosely packed, slightly moist. Sand, coarse; gravel, fine to medium subrounded to subangular schist and siltstone (roadstone).				
				Gravelly SAND, brownish orange, loosely packed, slightly moist. Sand, fine (micaeous - schist derived?); gravel, coarse subangular schist and trace siltstone.				
				Sandy GRAVEL, with trace clay, light brownish grey, loosely packerd, slightly moist. Gravel, fine to coarse and cobble sized, rounded river gravels or various origins, some angular schist; sand, medium; clay, locally absent.				
				Gravelly SAND, brownish orange, loosely packed, slightly moist. Sand, fine to medium (schist derived); gravel, coarse and cobble sized rounded river gravels, subangular schist and roadstone.				
				SAND with some gravel, and trace clay, medium orange brown, loosely packed, slightly moist. Sand, fine to medium, schist derived (micaeous); gravel, medium to coarse rounded river gravel & rare schist.				
		FILL		CLAY, with some boulders, minor gravel and minor sand, brownish orange, firm, moderately plastic. Gravel, fine to medium rounded river gravel (various origins), decreasing with depth Rootlets common.				
				From 1.2m, with bioclastic limestone boulders, slightly weathered, maximum 300mm diameter				
1								1

Shear Vane Factor (as per NZGS Guideline)

Comments : **TP 1200mm (width) x 2500mm (length). TP remained dry & stable throughout**

CLIENT: **Transit New Zealand**
PROJECT: **SH60 Eureka Bend**
LOCATION: **Eureka Bend**
JOB No.: **5125338**
LOGGED BY: **ARM**
CHECKED BY:
COMMENCED: **5/10/07**
COMPLETED: **5/10/07**

Testpit No.: TP102

Page: 2 of 4

CONTRACTOR: **SOLLY**
EQUIPMENT: **Hitachi EX20**
X-COORDINATE:
Y-COORDINATE:
R.L. SURFACE (m):
TOTAL DEPTH (m): **4.0m**

LOG OF TESTPIT

Depth (m)	Geological Formation	GEOLOGICAL DESCRIPTION (weathering, relative strength, colour, name, defect type, lithological features, bedding, foliation, mineralogy, cement etc)	Graphic Log	MATERIAL DESCRIPTION (colour, classification, strength, water content, plasticity, grading, etc)	Piezometer Details and Water Levels	DCP blows per 100mm (0 5 15 25)	Shear Vane (kPa)	Depth (m)
		FILL		CLAY continued				
				At 1.5m, 1500mm diameter limestone boulder, slightly weathered.				
2								2

Shear Vane Factor (as per NZGS Guideline)

Comments : **TP 1200mm (width) x 2500mm (length). TP remained dry & stable throughout**

CLIENT: **Transit New Zealand**
PROJECT: **SH60 Eureka Bend**
LOCATION: **Eureka Bend**
JOB No.: **5125338**
LOGGED BY: **ARM**
CHECKED BY:
COMMENCED: **5/10/07**
COMPLETED: **5/10/07**

Testpit No.: TP102

CONTRACTOR: **SOLLY**
EQUIPMENT: **Hitachi EX20**
X-COORDINATE:
Y-COORDINATE:
R.L. SURFACE (m):
TOTAL DEPTH (m): **4.0m**

LOG OF TESTPIT

Depth (m)	Geological Formation	GEOLOGICAL DESCRIPTION (weathering, relative strength, colour, name, defect type, lithological features, bedding, foliation, mineralogy, cement etc)	Graphic Log	MATERIAL DESCRIPTION (colour, classification, strength, water content, plasticity, grading, etc)	Piezometer Details and Water Levels	DCP blows per 100mm (0 5 15 25)	Shear Vane (kPa)	Depth (m)
		FILL		Sandy CLAY continued				
		FILL		Sandy CLAY with some cobbles and boulders, light yellowish orange, soft to firm, moist, moderately plastic. Sand, medium to coarse, derived from limestone; cobbles and boulders, maximum 400mm diameter, subangular to angular calcified limestone.				
3								3

Shear Vane
Factor (as per NZGS Guideline)

Comments : **TP 1200mm (width) x 2500mm (length). TP remained dry & stable throughout**

CLIENT: **Transit New Zealand**
PROJECT: **SH60 Eureka Bend**
LOCATION: **Eureka Bend**
JOB No.: **5125338**
LOGGED BY: **ARM**
CHECKED BY:
COMMENCED: **5/10/07**
COMPLETED: **5/10/07**

Testpit No.: TP102

CONTRACTOR: **SOLLY**
EQUIPMENT: **Hitachi EX20**
X-COORDINATE:
Y-COORDINATE:
R.L. SURFACE (m):
TOTAL DEPTH (m): **4.0m**

LOG OF TESTPIT

Depth (m)	Geological Formation	GEOLOGICAL DESCRIPTION (weathering, relative strength, colour, name, defect type, lithological features, bedding, foliation, mineralogy, cement etc)	Graphic Log	MATERIAL DESCRIPTION (colour, classification, strength, water content, plasticity, grading, etc)	Piezometer Details and Water Levels	DCP blows per 100mm (0 5 15 25)	Shear Vane (kPa)	Depth (m)
		FILL		Sandy CLAY continued END OF TESTPIT (4.0m) Unable to Excavate (Boulder)				
4								4

Shear Vane
Factor (as per NZGS Guideline)

Comments : **TP 1200mm (width) x 2500mm (length). TP remained dry & stable throughout**

GHD

CLIENT: **Transit**
PROJECT: **SH60 Eureka Bend**
LOCATION: **Hillside downslope of Eureka Bend**
JOB No.: **512533801**
LOGGED BY: **Anna Mills**
CHECKED BY:
COMMENCED: **11/03/08**
COMPLETED: **11/03/08**

Testpit No.: TP201

Page: **1 of 1**

CONTRACTOR: **Fulton Hogan**
EQUIPMENT: **Hitachi Zaxis 120 Excavator**
X-COORDINATE:
Y-COORDINATE:
R.L. SURFACE (m):
TOTAL DEPTH (m): **4.2**

LOG OF TESTPIT

Depth (m)	Geological Formation	GEOLOGICAL DESCRIPTION (weathering, relative strength, colour, name, defect type, lithological features, bedding, foliation, mineralogy, cement etc)	Graphic Log	MATERIAL DESCRIPTION (colour, classification, strength, water content, plasticity, grading, etc)	Piezometer Details and Water Levels	DCP blows per 100mm (0 5 10 17)	Shear Vane (kPa)	Depth (m)
0		Recent		Topsoil; brown. Firm, slightly moist. Rootlets present. Angular limestone boulders at surface.	Groundwater not encountered			
				Clayey SILT with trace very fine sand; light orange brown. Firm, slightly moist, low to moderate plasticity, non-dilatant, trace rootlets. Clay/silt proportions locally variable.			60	
1				Silty CLAY with some limestone boulders and trace fine sand; light yellowish brown. Firm to stiff, slightly moist, moderate to high plasticity, trace rootlets. Silt, micaceous; slightly weathered limestone boulders, moderately to very strong, rilled, locally with iron staining, maximum 1.2m diameter.			78/28 W wall of TP 84/40	1
				From 1.8m: becoming moist				
2							E wall of TP 49/25	2
3	Nile Group	Slightly weathered, light bluish grey, indistinctly bedded LIMESTONE; strong to very strong. (TAKAKA LIMESTONE)		Upper contact with clay undulating and varying between 2.0m and 3.2m bgl. Contact sloping 5 degrees downslope. No defects or bedding visible; upper contact displaying rilling.				3
4								4
5								5

Shear Vane Factor (as per NZGS Guideline)

Comments **Test pit remained dry and stable throughout. TP 14.4m length x 4.4m width.**

GHD

CLIENT: **Transit**
PROJECT: **SH60 Eureka Bend**
LOCATION: **Hillside downslope of Eureka Bend**
JOB No.: **512533801**
LOGGED BY: **Anna Mills**
CHECKED BY:
COMMENCED: **11/03/08**
COMPLETED: **11/03/08**

Testpit No.: TP202

Page: **1 of 2**

CONTRACTOR: **Fulton Hogan**
EQUIPMENT: **Hitachi Zaxis 120**
X-COORDINATE:
Y-COORDINATE:
R.L. SURFACE (m):
TOTAL DEPTH (m): **5.2**

LOG OF TESTPIT

Depth (m)	Geological Formation	GEOLOGICAL DESCRIPTION (weathering, relative strength, colour, name, defect type, lithological features, bedding, foliation, mineralogy, cement etc)	Graphic Log	MATERIAL DESCRIPTION (colour, classification, strength, water content, plasticity, grading, etc)	Piezometer Details and Water Levels	DCP blows per 100mm (0 5 10 17)	Shear Vane (kPa)	Depth (m)
0		Fill		Topsoil; brown. Firm, slightly moist. Rootlets present. Angular limestone boulders at surface.	No groundwater encountered			
				Silty CLAY with some boulders; light yellowish brown, locally mottled orange. Stiff, slightly moist, moderate plasticity, rootlets present. Clay/silt proportions locally variable. Subrounded , slightly weathered limestone, angular, slightly weathered schist boulders and rounded siltstone boulders. Lower contact sloping at 28 degrees downslope.				
1								1
2		Recent		Clayey SILT; brown. Stiff, slightly moist, low plasticity. Rootlets throughout. Originally topsoil				2
				Clayey SILT; light brown. Stiff, slightly moist, low plasticity. Silt, micaceous; trace rootlets.			110/55	
3								3
4				Clayey SILT with some boulders; light brown. Stiff, slightly moist, low plasticity. Subrounded, slightly weathered limestone boulders with rilled surfaces. At 4.5m: 1.5m diameter limestone boulder				4
5								5

Shear Vane Factor (as per NZGS Guideline)

Comments **Test pit remained dry and stable throughout. Test pit 8.5m length x 3m width.**

LOG OF TESTPIT

Testpit No.: TP202

Page: 2 of 2

CLIENT: Transit
PROJECT: SH60 Eureka Bend
LOCATION: Hillside downslope of Eureka Bend
JOB No.: 512533801
LOGGED BY: Anna Mills
CHECKED BY:
COMMENCED: 11/03/08
COMPLETED: 11/03/08
CONTRACTOR: Fulton Hogan
EQUIPMENT: Hitachi Zaxis 120
X-COORDINATE:
Y-COORDINATE:
R.L. SURFACE (m):
TOTAL DEPTH (m): 5.2

Depth (m)	Geological Formation	GEOLOGICAL DESCRIPTION (weathering, relative strength, colour, name, defect type, lithological features, bedding, foliation, mineralogy, cement etc)	Graphic Log	MATERIAL DESCRIPTION (colour, classification, strength, water content, plasticity, grading, etc)	Piezometer Details and Water Levels	DCP blows per 100mm (0 5 10 17)	Shear Vane (kPa)	Depth (m)
	Nile	Slightly weathered, light bluish grey, indistinctly bedded LIMESTONE; strong to very strong. (TAKAKA LIMESTONE)		Upper contact with clay sloping at 5 degrees downslope. No defects or bedding visible.				
6								6
7								7
8								8
9								9
10								10

Shear Vane
Factor (as per NZGS Guideline)

Comments **Test pit remained dry and stable throughout. Test pit 8.5m length x 3m width.**

LOG OF TESTPIT

Testpit No.: TP203

Page: 1 of 1

CLIENT: Transit
PROJECT: SH60 Eureka Bend
LOCATION: Hillside downslope of Eureka Bend
JOB No.: 512533801
LOGGED BY: Anna Mills
CHECKED BY:
COMMENCED: 12/03/08
COMPLETED: 12/03/08
CONTRACTOR: Fulton Hogan
EQUIPMENT: Hitachi Zaxis 120
X-COORDINATE:
Y-COORDINATE:
R.L. SURFACE (m):
TOTAL DEPTH (m): 4.0

Depth (m)	Geological Formation	GEOLOGICAL DESCRIPTION (weathering, relative strength, colour, name, defect type, lithological features, bedding, foliation, mineralogy, cement etc)	Graphic Log	MATERIAL DESCRIPTION (colour, classification, strength, water content, plasticity, grading, etc)	Piezometer Details and Water Levels	DCP blows per 100mm (0 5 10 17)	Shear Vane (kPa)	Depth (m)
		Fill		Topsoil; brown. Stiff, slightly moist.				
				Silty gravelly/cobbly CLAY; light brown. Firm to stiff, slightly moist, moderate plasticity. Angular schist, subrounded slightly weathered limestone and rounded siltstone gravel and cobbles.				
1								1
				CLAY with some silt and trace cobbles; light orange brown. Stiff, slightly moist, moderate to high plasticity; angular schist gravel. Some rootlets.				
				Silty CLAY with some cobbles, greyish brown locally mottled orange. Stiff, slightly moist, moderate plasticity; subrounded, rilled, slightly weathered limestone, angular schist and rounded siltstone cobbles and boulders. Some rootlets.	~No groundwater encountered			
2								2
		Recent		CLAY with some silt; reddish brown. Very stiff to stiff, slightly moist, low to moderate plasticity.				
3								3
	Nile Group	Slightly weathered to unweathered, light bluish grey, bedded bioclastic LIMESTONE; very strong to extremely strong. (TAKAKA LIMESTONE)		Bedding plane at 46/242 (dip/dip direction).				
4								4
5								5

Shear Vane
Factor (as per NZGS Guideline)

Comments **Test pit remained dry and stable throughout. TP 1.5m width x 4.0m length.**

CLIENT: Transit
PROJECT: SH60 Eureka Bend
LOCATION: Hillside downslope of Eureka Bend
JOB No.: 512533801
LOGGED BY: Anna Mills
CHECKED BY:
COMMENCED: 12/03/08
COMPLETED: 12/03/08

Testpit No.: TP204

Page: 1 of 1

CONTRACTOR: Fulton Hogan
EQUIPMENT: Hitachi Zaxis 120
X-COORDINATE:
Y-COORDINATE:
R.L. SURFACE (m):
TOTAL DEPTH (m): 3.1

LOG OF TESTPIT

Depth (m)	Geological Formation	GEOLOGICAL DESCRIPTION (weathering, relative strength, colour, name, defect type, lithological features, bedding, foliation, mineralogy, cement etc)	Graphic Log	MATERIAL DESCRIPTION (colour, classification, strength, water content, plasticity, grading, etc)	Piezometer Details and Water Levels	DCP blows per 100mm (0 5 10 17)	Shear Vane (kPa)	Depth (m)
	Nile Group	Fill		Topsoil; brown. Firm, slightly moist, rootlets present.	– No groundwater encountered			
				Clayey sandy SILT with some gravel and cobbles; light greyish brown locally mottled yellow. Firm to stiff, slightly moist; silt, micaceous; angular schist, angular marble and subrounded slightly weathered limestone cobbles.				
1		Recent		Clayey SILT; brown. Stiff, slightly moist, low to moderate plasticity; rootlets present. Upper contact sloping at 28 degrees; former ground surface (topsoil).				1
				Clayey SILT; light yellowish brown. Stiff, slightly moist, low to moderate plasticity.			80/40	
2							84/28	2
							32/18	
		Slightly to moderately weathered, dark bluish grey, indistinctly bedded LIMESTONE; strong to very strong. (TAKAKA LIMESTONE)		Upper contact with clay subhorizontal, undulating. No defects or bedding visible.				
3								3
4								4
5								5

Shear Vane Factor (as per NZGS Guideline)

Comments **Test pit remained dry and stable throughout. Test pit 3.5m (length) x 1.5m (width).**

CLIENT: Transit
PROJECT: SH60 Eureka Bend
LOCATION: Toe of landslip downslope of Eureka Bend
JOB No.: 512533801
LOGGED BY: Anna Mills
CHECKED BY:
COMMENCED: 12/03/08
COMPLETED: 12/03/08

Testpit No.: TP205

Page: 1 of 1

CONTRACTOR: Fulton Hogan
EQUIPMENT: Hitachi Zaxis 120
X-COORDINATE:
Y-COORDINATE:
R.L. SURFACE (m):
TOTAL DEPTH (m): 1.6

LOG OF TESTPIT

Depth (m)	Geological Formation	GEOLOGICAL DESCRIPTION (weathering, relative strength, colour, name, defect type, lithological features, bedding, foliation, mineralogy, cement etc)	Graphic Log	MATERIAL DESCRIPTION (colour, classification, strength, water content, plasticity, grading, etc)	Piezometer Details and Water Levels	DCP blows per 100mm (0 5 10 17)	Shear Vane (kPa)	Depth (m)
		Recent		Topsoil; brown. Slightly moist, low plasticity.	– No groundwater encountered			
1				Clayey SILT, light yellowish brown. Stiff, slightly moist, low plasticity. Rootlet present.				1
		Slightly weathered to unweathered, light bluish grey, indistinctly bedded LIMESTONE; strong to very strong. (TAKAKA LIMESTONE)		Surface subhorizontal. No defects or bedding visible.				
2								2
3								3
4								4
5								5

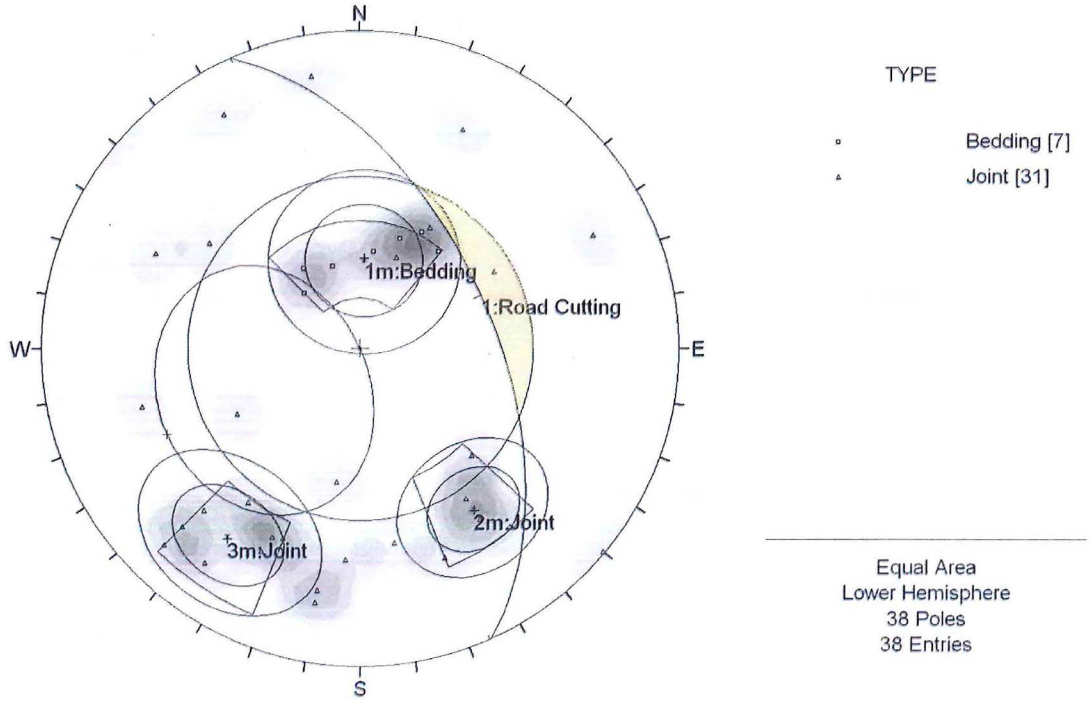
Shear Vane Factor (as per NZGS Guideline)

Comments **Test pit remained dry and stable throughout. Test pit 1.5m (width) x 4.0m (length).**

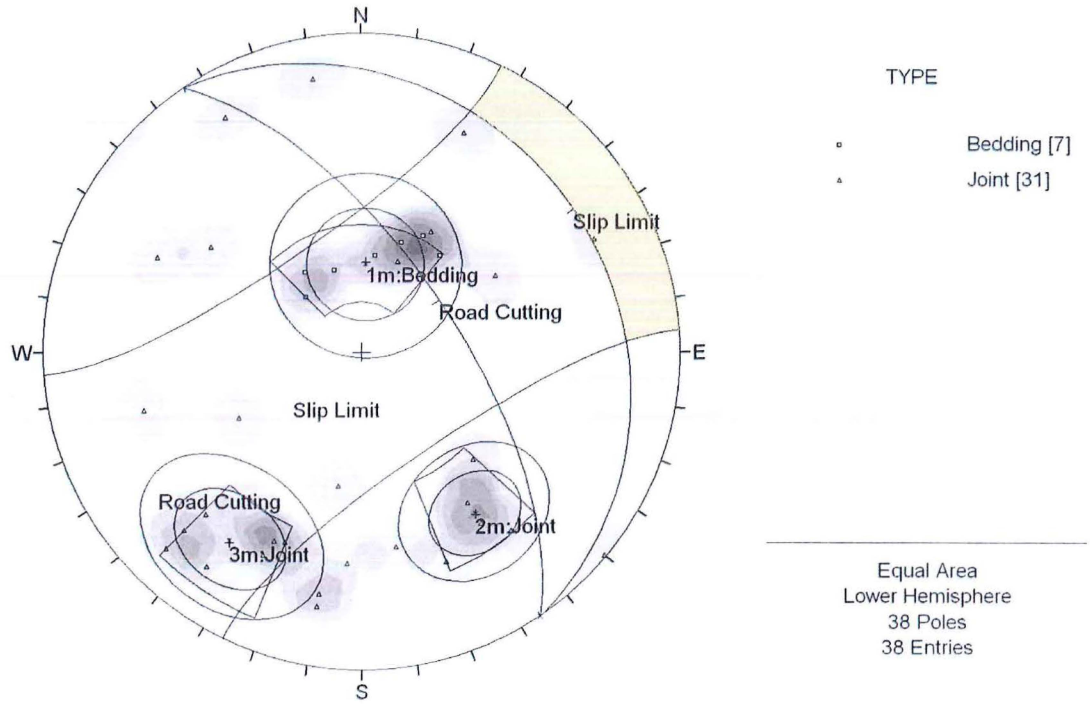
Appendix 3

Additional Kinematic Analysis

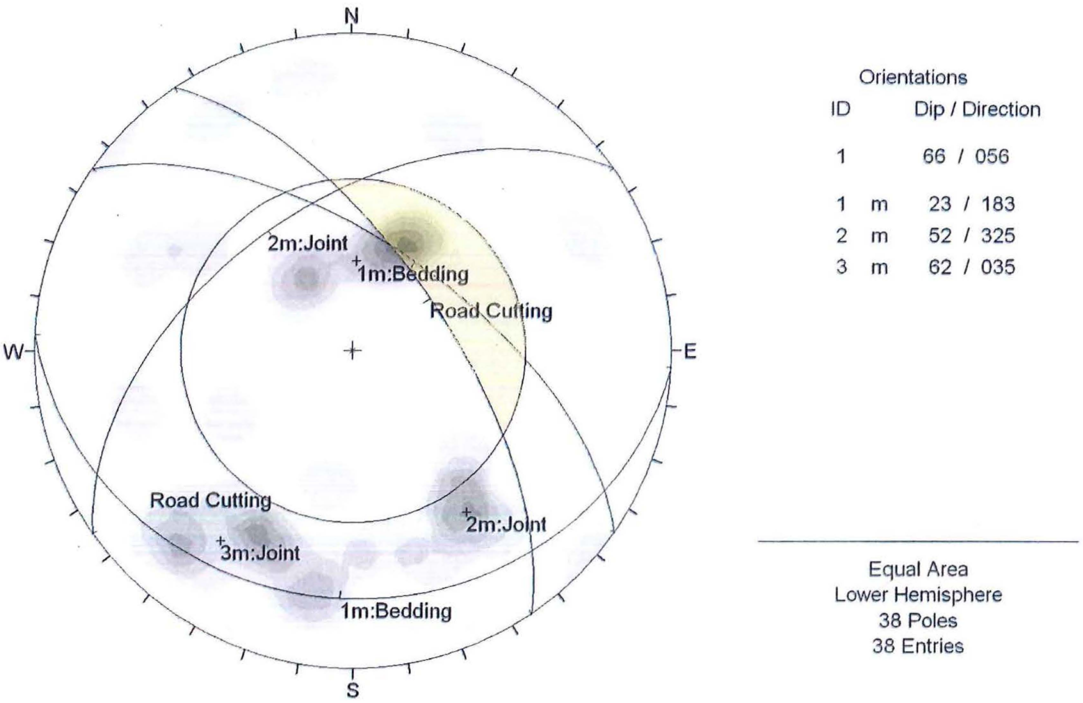
1. Additional Planar Failure Analysis
2. Additional Toppling Failure Analysis
3. Additional Wedge Failure Analysis



Appendix 3-1: Potential for planar failure along defects road cutting is in its current orientation. The yellow zone encompasses poles that have the potential to fail. Angle of internal friction equals 45°. Clearly there is a very low chance of planar failure as only one pole plots within the failure envelope.



Appendix 3-2: Potential for toppling failure along defects road cutting is in its current orientation. The yellow zone encompasses poles that have the potential to fail. Angle of internal friction equals 45°. Clearly there is a very low chance of toppling failure as only one pole plots within the failure envelope.



Appendix 3-3: Potential for wedge failure along defect intersections on the current road cutting orientation. The yellow zone encompasses intersections of planes that have the potential to fail. The angle of internal friction equals 45°. Because no defect planes intersect within the failure envelope the probability of a wedge failure occurring is low.

Appendix 4

Eureka Bend Rock Trajectory Analysis

Colorado Rockfall Simulation Program (CRSP)

Results below are from rock trajectory analysis done using the Colorado Rockfall Simulation Program (CRSP) Version 4.

Test Run – Original Profile

CRSP Input File -c:\documents and settings\all users\desktop\Tim\CRSP Original.dat

Input File Specifications
Units of Measure: Metric
Total Number of Cells: 20
Analysis Point 1 X-Coordinate: 65
Analysis Point 2 X-Coordinate: 92
Analysis Point 3 X-Coordinate:
Initial Y-Top Starting Zone Coordinate: 395
Initial Y-Base Starting Zone Coordinate: 360

Cell Data

Cell No.	S.R.	Tang. C.	Norm. C.	Begin X	Begin Y	End X	End Y
1	0.4	0.83	0.3	0	397	5	395
2	0.4	0.83	0.3	5	395	16	390
3	0.4	0.83	0.3	16	390	24	385
4	0.4	0.83	0.3	24	385	32	380
5	0.4	0.83	0.3	32	380	40	375
6	0.4	0.83	0.3	40	375	50	370
7	1	0.83	0.3	50	370	56	365
8	1	0.8	0.3	56	365	60	360
9	2	0.8	0.3	60	360	67	355
10	4	0.8	0.3	67	355	74	350
11	4	0.8	0.3	74	350	77	345
12	2	0.8	0.3	77	345	82	340
13	2	0.8	0.3	82	340	87	335
14	1.6	0.8	0.3	87	335	91	330
15	0.2	0.87	0.35	91	330	92	325
16	0	0.92	0.42	92	325	121	320
17	1	0.81	0.3	121	320	127	315
18	1	0.81	0.3	127	315	132	310
19	1	0.81	0.3	132	310	138	305
20	1	0.81	0.3	138	305	146	300

CRSP Simulation Specifications: Used with c:\documents and settings\all users\desktop\Tim\CRSP Original.dat

Total Number of Rocks Simulated: 500
Starting Velocity in X-Direction: 0.3 m/sec
Starting Velocity in Y-Direction: -0.3 m/sec
Starting Cell Number: 1
Ending Cell Number: 20
Rock Density: 2646 kg/m^3
Rock Shape: Spherical
Diameter: 1 m

CRSP Analysis Point 1 Data - c:\documents and settings\all users\desktop\Tim\CRSP Original.dat
Analysis Point 1: X = 65, Y = 356
Total Rocks Passing Analysis Point: 36

Cumulative Probability	Velocity (m/sec)	Energy (J)	Bounce Ht. (m)
50%	5.66	29951	0.26
75%	6.76	41495	3.85
90%	7.74	51877	7.07
95%	8.33	58111	9.01
98%	9	65107	11.18

Velocity (m/sec)	Bounce Height (m)	Kinetic Energy (J)
Maximum: 9.95	Maximum: 1.54	Maximum: 86721
Average: 5.66	Average: .49	Average: 29951
Minimum: 3.07	G. Mean: .26	Std. Dev.: 17096
Std. Dev.: 1.62	Std. Dev.: 5.31	

CRSP Analysis Point 2 Data - c:\documents and settings\all users\desktop\Tim\CRSP Original.dat
Analysis Point 2: X = 92, Y = 325
Total Rocks Passing Analysis Point: 10

Cumulative Probability	Velocity (m/sec)	Energy (J)	Bounce Ht. (m)
50%	13.33	150912	5.17
75%	15.95	206077	6.12
95%	19.72	285482	7.5
98%	21.31	318914	8.08

Velocity (m/sec)	Bounce Height (m)	Kinetic Energy (J)
Maximum: 18.78	Maximum: 8.52	Maximum: 282162
Average: 13.33	Average: 5.45	Average: 150912
Minimum: 8.11	G. Mean: 5.17	Std. Dev.: 81700
Std. Dev.: 3.88	Std. Dev.: 1.41	

CRSP Data Collected at End of Each Cell - c:\documents and settings\all users\desktop\Tim\CRSP Original.dat
Velocity Units: m/sec Bounce Height Units: m

Cell #	Max. Vel.	Avg. Vel.	S.D. Vel.	Max. Bounce Ht.	Avg. Bounce Ht.
1	No rocks	past end of cell			
2	No rocks	past end of cell			
3	3	3	0	0	-1
4	2	2	0	0	0
5	3	2	0	0	0
6	2	1	0	0	0
7	7	4	1.53	1	0
8	10	5	2	2	0
9	9	6	1.69	2	0
10	13	7	2.39	1	0
11	16	10	2.68	4	1
12	16	8	3.49	3	0
13	15	10	3.52	3	1
14	18	12	4.33	4	1
15	19	13	3.88	9	5
16	No rocks	past end of cell			
17	No rocks	past end of cell			
18	No rocks	past end of cell			
19	No rocks	past end of cell			
20	No rocks	past end of cell			

CRSP Rocks Stopped Data - c:\documents and settings\all users\desktop\Tim\CRSP Original.dat

X Interval	Rocks Stopped
0 To 10 m	72
10 To 20 m	32
20 To 30 m	89
30 To 40 m	90
40 To 50 m	72
50 To 60 m	81
60 To 70 m	40
70 To 80 m	11
80 To 90 m	2
90 To 100 m	3
100 To 110 m	8
110 To 120 m	0
120 To 130 m	0
130 To 140 m	0
140 To 146 m	0

Test Run – Design 1

CRSP Input File -c:\documents and settings\all users\desktop\Tim\CRSP Design 1.dat

Input File Specifications
Units of Measure: Metric
Total Number of Cells: 17
Analysis Point 1 X-Coordinate: 65
Analysis Point 2 X-Coordinate: 74
Analysis Point 3 X-Coordinate:
Initial Y-Top Starting Zone Coordinate: 395
Initial Y-Base Starting Zone Coordinate: 360

Cell Data

Cell No.	S.R.	Tang. C.	Norm. C.	Begin X	Begin Y	End X	End Y
1	0.4	0.83	0.3	0	397	5	395
2	0.4	0.83	0.3	5	395	16	390
3	0.4	0.83	0.3	16	390	24	385
4	0.4	0.83	0.3	24	385	32	380
5	0.4	0.83	0.3	32	380	40	375
6	0.4	0.83	0.3	40	375	50	370
7	1	0.83	0.3	50	370	56	365
8	1	0.8	0.3	56	365	60	360
9	2	0.8	0.3	60	360	67	355
10	4	0.8	0.3	67	355	76	348
11	0	0.9	0.4	76	348	82	323
12	2	0.92	0.42	82	323	105	323
13	2	0.92	0.42	105	323	121	320
14	1	0.81	0.3	121	320	127	315
15	1	0.81	0.3	127	315	132	310
16	1	0.81	0.3	132	310	138	305
17	1	0.81	0.3	138	305	146	300

CRSP Simulation Specifications: Used with c:\documents and settings\all users\desktop\Tim\CRSP Design 1.dat
Total Number of Rocks Simulated: 500
Starting Velocity in X-Direction: 0.3 m/sec
Starting Velocity in Y-Direction: -0.3 m/sec
Starting Cell Number: 1
Ending Cell Number: 17
Rock Density: 2646 kg/m^3
Rock Shape: Spherical
Diameter: 1 m

CRSP Analysis Point 1 Data - c:\documents and settings\all users\desktop\Tim\CRSP Design 1.dat
Analysis Point 1: X = 65, Y = 356
Total Rocks Passing Analysis Point: 27

Cumulative Probability	Velocity (m/sec)	Energy (J)	Bounce Ht. (m)
50%	5.86	31794	0.23
75%	7.19	47034	3
90%	8.38	60741	5.48
95%	9.1	68971	6.98
98%	9.9	78207	8.65

Velocity (m/sec)	Bounce Height (m)	Kinetic Energy (J)
Maximum: 11.86	Maximum: .91	Maximum: 114494
Average: 5.86	Average: .38	Average: 31794
Minimum: 2.95	G. Mean: .23	Std. Dev.: 22570
Std. Dev.: 1.97	Std. Dev.: 4.09	

CRSP Analysis Point 2 Data - c:\documents and settings\all users\desktop\Tim\CRSP Design 1.dat

Analysis Point 2: X = 74, Y = 350

Total Rocks Passing Analysis Point: 12

Cumulative Probability	Velocity (m/sec)	Energy (J)	Bounce Ht. (m)
50%	7.91	58728	0.82
75%	9.4	79793	2.31
90%	10.74	98740	3.64
95%	11.54	110115	4.45
98%	12.45	122882	5.35

Velocity (m/sec)	Bounce Height (m)	Kinetic Energy (J)
Maximum: 11.35	Maximum: 2.08	Maximum: 117436
Average: 7.91	Average: 1.04	Average: 58728
Minimum: 4.43	G. Mean: .82	Std. Dev.: 31198
Std. Dev.: 2.21	Std. Dev.: 2.2	

CRSP Data Collected at End of Each Cell - c:\documents and settings\all users\desktop\Tim\CRSP Design 1.dat

Velocity Units: m/sec Bounce Height Units: m

Cell #	Max. Vel.	Avg. Vel.	S.D. Vel.	Max. Bounce Ht.	Avg. Bounce Ht.
1	No rocks	past end of cell			
2	No rocks	past end of cell			
3	3	3	0	0	0
4	3	2	0	0	0
5	3	3	0	0	0
6	2	1	0	0	0
7	7	4	1.8	1	0
8	10	5	1.88	2	0
9	11	6	2.45	1	0
10	12	8	2.92	2	0
11	23	16	2.9	22	15
12	No rocks	past end of cell			
13	No rocks	past end of cell			
14	No rocks	past end of cell			
15	No rocks	past end of cell			
16	No rocks	past end of cell			
17	No rocks	past end of cell			

CRSP Rocks Stopped Data - c:\documents and settings\all users\desktop\Tim\CRSP Design 1.dat

X Interval	Rocks Stopped
0 To 10 m	72
10 To 20 m	32
20 To 30 m	90
30 To 40 m	89
40 To 50 m	73
50 To 60 m	89
60 To 70 m	38
70 To 80 m	6
80 To 90 m	7
90 To 100 m	4
100 To 110 m	0
110 To 120 m	0
120 To 130 m	0
130 To 140 m	0
140 To 146 m	0

Test Run – Design 1 with rock catch fence

CRSP Input File -c:\documents and settings\all users\desktop\Tim\CRSP Design 1 Fence.dat

Input File Specifications
Units of Measure: Metric
Total Number of Cells: 17
Analysis Point 1 X-Coordinate: 65
Analysis Point 2 X-Coordinate: 74
Analysis Point 3 X-Coordinate: 82
Initial Y-Top Starting Zone Coordinate: 395
Initial Y-Base Starting Zone Coordinate: 360

Cell Data

Cell No.	S.R.	Tang. C.	Norm. C.	Begin X	Begin Y	End X	End Y
1	0.4	0.83	0.3	0	397	5	395
2	0.4	0.83	0.3	5	395	16	390
3	0.4	0.83	0.3	16	390	24	385
4	0.4	0.83	0.3	24	385	32	380
5	0.4	0.83	0.3	32	380	40	375
6	0.4	0.83	0.3	40	375	50	370
7	1	0.83	0.3	50	370	56	365
8	1	0.8	0.3	56	365	60	360
9	2	0.8	0.3	60	360	67	355
10	4	0.8	0.3	67	355	75	348
11	0	0.9	0.4	75	351	76	351
12	0	0.9	0.4	76	348	82	323
13	2	0.92	0.42	82	323	105	323
14	2	0.92	0.42	105	323	121	320
15	1	0.81	0.3	121	320	127	315
16	1	0.81	0.3	127	315	132	310
17	1	0.81	0.3	132	310	138	305

CRSP Simulation Specifications: Used with c:\documents and settings\all users\desktop\Tim\CRSP Design 1 Fence.dat
Total Number of Rocks Simulated: 500
Starting Velocity in X-Direction: 0.3 m/sec
Starting Velocity in Y-Direction: -0.3 m/sec
Starting Cell Number: 1
Ending Cell Number: 17
Rock Density: 2646 kg/m^3
Rock Shape: Spherical
Diameter: 1 m

CRSP Analysis Point 1 Data - c:\documents and settings\all users\desktop\Tim\CRSP Design 1 Fence.dat
Analysis Point 1: X = 65, Y = 356
Total Rocks Passing Analysis Point: 24

Cumulative Probability	Velocity (m/sec)	Energy (J)	Bounce Ht. (m)
50%	5.2	26485	0.4
75%	6.57	39328	2.51
90%	7.79	50879	4.41
95%	8.53	57814	5.55
98%	9.36	65597	6.83

Velocity (m/sec)	Bounce Height (m)	Kinetic Energy (J)
Maximum: 9.8	Maximum: 1.13	Maximum: 77412
Average: 5.2	Average: .57	Average: 26485
Minimum: 2.04	G. Mean: .4	Std. Dev.: 19020
Std. Dev.: 2.02	Std. Dev.: 3.13	

CRSP Analysis Point 2 Data - c:\documents and settings\all users\desktop\Tim\CRSP Design 1 Fence.dat
Analysis Point 2: X = 74, Y = 349
Total Rocks Passing Analysis Point: 11

Cumulative Probability	Velocity (m/sec)	Energy (J)	Bounce Ht. (m)
50%	8.09	57204	0.3
75%	9.57	79733	5.78
90%	10.91	99997	10.71
95%	11.71	112162	13.66
98%	12.61	125816	16.98

Velocity (m/sec)	Bounce Height (m)	Kinetic Energy (J)
Maximum: 13.68	Maximum: 1.9	Maximum: 146453
Average: 8.09	Average: .66	Average: 57204
Minimum: 5.29	G. Mean: .3	Std. Dev.: 33366
Std. Dev.: 2.2	Std. Dev.: 8.11	

CRSP Analysis Point 3 Data - c:\documents and settings\all users\desktop\Tim\CRSP Design 1 Fence.dat
Analysis Point 3: X = 82, Y = 323

NO ROCKS PAST ANALSYSIS POINT 3

CRSP Data Collected at End of Each Cell - c:\documents and settings\all users\desktop\Tim\CRSP Design 1 Fence.dat
Velocity Units: m/sec Bounce Height Units: m

Cell #	Max. Vel.	Avg. Vel.	S.D. Vel.	Max. Bounce Ht.	Avg. Bounce Ht.
1	No rocks	past end of cell			
2	No rocks	past end of cell			
3	3	3	0	0	0
4	2	2	0	0	0
5	3	2	0	0	0
6	3	2	0	0	0
7	7	4	1.83	0	0
8	12	5	2.18	2	0
9	9	5	1.91	1	0
10	11	8	2.41	2	0
11	No rocks	past end of cell			
12	No rocks	past end of cell			
13	No rocks	past end of cell			
14	No rocks	past end of cell			
15	No rocks	past end of cell			
16	No rocks	past end of cell			
17	No rocks	past end of cell			

CRSP Rocks Stopped Data - c:\documents and settings\all users\desktop\Tim\CRSP Design 1 Fence.dat

X Interval	Rocks Stopped
0 To 10 m	72
10 To 20 m	33
20 To 30 m	90
30 To 40 m	88
40 To 50 m	73
50 To 60 m	87
60 To 70 m	41
70 To 80 m	16
80 To 90 m	0
90 To 100 m	0
100 To 110 m	0
110 To 120 m	0
120 To 130 m	0
130 To 138 m	0

CRSP Input File -c:\documents and settings\all users\desktop\Tim\CRSP Design 2.dat

Input File Specifications
Units of Measure: Metric
Total Number of Cells: 18
Analysis Point 1 X-Coordinate: 68
Analysis Point 2 X-Coordinate: 78
Analysis Point 3 X-Coordinate:
Initial Y-Top Starting Zone Coordinate: 395
Initial Y-Base Starting Zone Coordinate: 360

Cell Data

Cell No.	S.R.	Tang. C.	Norm. C.	Begin X	Begin Y	End X	End Y
1	0.4	0.83	0.3	0	397	5	395
2	0.4	0.83	0.3	5	395	16	390
3	0.4	0.83	0.3	16	390	24	385
4	0.4	0.83	0.3	24	385	32	380
5	0.4	0.83	0.3	32	380	40	375
6	0.4	0.83	0.3	40	375	50	370
7	1	0.83	0.3	50	370	56	365
8	1	0.8	0.3	56	365	60	360
9	2	0.8	0.3	60	360	67	355
10	0	0.9	0.4	67	355	72	338
11	0	0.9	0.4	72	338	78	338
12	0	0.9	0.4	78	338	82	323
13	0	0.92	0.42	82	323	105	323
14	0	0.92	0.42	105	323	121	320
15	1	0.81	0.3	121	320	127	315
16	1	0.81	0.3	127	315	132	310
17	1	0.81	0.3	132	310	138	305
18	1	0.81	0.3	138	305	146	300

CRSP Simulation Specifications: Used with c:\documents and settings\all users\desktop\Tim\CRSP Design 2.dat

Total Number of Rocks Simulated: 500
Starting Velocity in X-Direction: 0.3 m/sec
Starting Velocity in Y-Direction: -0.3 m/sec
Starting Cell Number: 1
Ending Cell Number: 18
Rock Density: 2646 kg/m^3
Rock Shape: Spherical
Diameter: 1 m

CRSP Analysis Point 1 Data - c:\documents and settings\all users\desktop\Tim\CRSP Design 2.dat
Analysis Point 1: X = 68, Y = 352
Total Rocks Passing Analysis Point: 27

Cumulative Probability	Velocity (m/sec)	Energy (J)	Bounce Ht. (m)
50%	8.05	55159	2.57
75%	9.36	72222	3.63
90%	10.55	87569	4.58
95%	11.26	96783	5.15
98%	12.05	107124	5.8

Velocity (m/sec)	Bounce Height (m)	Kinetic Energy (J)
Maximum: 12.21	Maximum: 4.07	Maximum: 119356
Average: 8.05	Average: 2.76	Average: 55159
Minimum: 4.53	G. Mean: 2.57	Std. Dev.: 25271
Std. Dev.: 1.95	Std. Dev.: 1.57	

CRSP Analysis Point 2 Data - c:\documents and settings\all users\desktop\Tim\CRSP Design 2.dat
Analysis Point 2: X = 78, Y = 338
Total Rocks Passing Analysis Point: 16

50%	6.88	55801	0.01
75%	10.08	110619	10.39
90%	12.96	159924	19.72
95%	14.7	189525	25.32
98%	16.64	222747	31.6

Velocity (m/sec)	Bounce Height (m)	Kinetic Energy (J)
Maximum: 19.47	Maximum: 2.61	Maximum: 280221
Average: 6.88	Average: .3	Average: 55801
Minimum: 3.22	G. Mean: .01	Std. Dev.: 81187
Std. Dev.: 4.75	Std. Dev.: 15.36	

CRSP Data Collected at End of Each Cell - c:\documents and settings\all users\desktop\Tim\CRSP Design 2.dat
Velocity Units: m/sec Bounce Height Units: m

Cell #	Max. Vel.	Avg. Vel.	S.D. Vel.	Max. Bounce Ht.	Avg. Bounce Ht.
1	No rocks	past end of cell			
2	No rocks	past end of cell			
3	3	2	0	0	0
4	2	2	0	0	0
5	3	2	0	0	0
6	1	1	0	0	0
7	6	4	1.35	1	0
8	9	5	2.08	1	0
9	11	6	2.44	1	0
10	19	14	3.24	13	7
11	19	7	4.75	3	0
12	24	12	5.7	14	11
13	No rocks	past end of cell			
14	No rocks	past end of cell			
15	No rocks	past end of cell			
16	No rocks	past end of cell			
17	No rocks	past end of cell			
18	No rocks	past end of cell			

CRSP Rocks Stopped Data - c:\documents and settings\all users\desktop\Tim\CRSP Design 2.dat

X Interval	Rocks Stopped
0 To 10 m	72
10 To 20 m	33
20 To 30 m	89
30 To 40 m	89
40 To 50 m	73
50 To 60 m	82
60 To 70 m	35
70 To 80 m	15
80 To 90 m	5
90 To 100 m	7
100 To 110 m	0
110 To 120 m	0
120 To 130 m	0
130 To 140 m	0
140 To 146 m	0

Test Run – Design 2 with aggregate on bench

CRSP Input File -c:\documents and settings\all users\desktop\Tim\CRSP Design 2b.dat

Input File Specifications
Units of Measure: Metric
Total Number of Cells: 18
Analysis Point 1 X-Coordinate: 68
Analysis Point 2 X-Coordinate: 78
Analysis Point 3 X-Coordinate:
Initial Y-Top Starting Zone Coordinate: 395
Initial Y-Base Starting Zone Coordinate: 360

Cell Data

Cell No.	S.R.	Tang. C.	Norm. C.	Begin X	Begin Y	End X	End Y
1	0.4	0.83	0.3	0	397	5	395
2	0.4	0.83	0.3	5	395	16	390
3	0.4	0.83	0.3	16	390	24	385
4	0.4	0.83	0.3	24	385	32	380
5	0.4	0.83	0.3	32	380	40	375
6	0.4	0.83	0.3	40	375	50	370
7	1	0.83	0.3	50	370	56	365
8	1	0.8	0.3	56	365	60	360
9	2	0.8	0.3	60	360	67	355
10	0	0.9	0.4	67	355	72	338
11	0	0.7	0.15	72	338	78	338
12	0	0.9	0.4	78	338	82	323
13	0	0.92	0.42	82	323	105	323
14	0	0.92	0.42	105	323	121	320
15	1	0.81	0.3	121	320	127	315
16	1	0.81	0.3	127	315	132	310
17	1	0.81	0.3	132	310	138	305
18	1	0.81	0.3	138	305	146	300

CRSP Simulation Specifications: Used with c:\documents and settings\all users\desktop\Tim\CRSP Design 2b.dat

Total Number of Rocks Simulated: 500
Starting Velocity in X-Direction: 0.3 m/sec
Starting Velocity in Y-Direction: -0.3 m/sec
Starting Cell Number: 1
Ending Cell Number: 18
Rock Density: 2646 kg/m^3
Rock Shape: Spherical
Diameter: 1 m

CRSP Analysis Point 1 Data - c:\documents and settings\all users\desktop\Tim\CRSP Design 2b.da
Analysis Point 1: X = 68, Y = 352
Total Rocks Passing Analysis Point: 18

Cumulative Probability	Velocity (m/sec)	Energy (J)	Bounce Ht. (m)
50%	7.23	45167	1.54
75%	8.36	57863	7.02
90%	9.38	69283	11.96
95%	9.99	76138	14.92
98%	10.68	83833	18.24

Velocity (m/sec)	Bounce Height (m)	Kinetic Energy (J)
Maximum: 10.96	Maximum: 4.12	Maximum: 90058
Average: 7.23	Average: 2.78	Average: 45167
Minimum: 4.59	G. Mean: 1.54	Std. Dev.: 18803
Std. Dev.: 1.67	Std. Dev.: 8.12	

CRSP Analysis Point 2 Data - c:\documents and settings\all users\desktop\Tim\CRSP Design 2b.dat
Analysis Point 2: X = 78, Y = 338
Total Rocks Passing Analysis Point: 4

Cumulative Probability	Velocity (m/sec)	Energy (J)	Bounce Ht. (m)
50%	4.08	16072	0
75%	4.08	16072	0.68
90%	4.08	16072	1.29
95%	4.08	16072	1.65
98%	4.08	16072	2.06

Velocity (m/sec)	Bounce Height (m)	Kinetic Energy (J)
Maximum: 4.54	Maximum: .01	Maximum: 19958
Average: 4.08	Average: -.02	Average: 16072
Minimum: 3.47	G. Mean: 0	Std. Dev.: 0
Std. Dev.: 0 Std. Dev.: 1		

CRSP Data Collected at End of Each Cell - c:\documents and settings\all users\desktop\Tim\CRSP Design 2b.dat
Velocity Units: m/sec Bounce Height Units: m

Cell #	Max. Vel.	Avg. Vel.	S.D. Vel.	Max. Bounce Ht.	Avg. Bounce Ht.
1	No rocks	past end of cell			
2	No rocks	past end of cell			
3	3	2	0	0	0
4	2	1	0	0	0
5	3	2	0	0	0
6	2	2	0	0	0
7	6	4	1.53	1	0
8	12	5	2.08	1	0
9	9	6	1.77	1	0
10	20	13	4.19	14	7
11	5	4	0	0	-1
12	13	11	0	11	9
13	No rocks	past end of cell			
14	No rocks	past end of cell			
15	No rocks	past end of cell			
16	No rocks	past end of cell			
17	No rocks	past end of cell			
18	No rocks	past end of cell			

CRSP Rocks Stopped Data - c:\documents and settings\all users\desktop\Tim\CRSP Design 2b.dat

X Interval	Rocks Stopped
0 To 10 m	72
10 To 20 m	33
20 To 30 m	89
30 To 40 m	90
40 To 50 m	72
50 To 60 m	81
60 To 70 m	45
70 To 80 m	14
80 To 90 m	4
90 To 100 m	0
100 To 110 m	0
110 To 120 m	0
120 To 130 m	0
130 To 140 m	0
140 To 146 m	0

Test Run – Design 2 with rock catch fence

CRSP Input File -c:\documents and settings\all users\desktop\Tim\CRSP Design 2 Fence.dat

Input File Specifications
Units of Measure: Metric
Total Number of Cells: 19
Analysis Point 1 X-Coordinate: 68
Analysis Point 2 X-Coordinate:
Analysis Point 3 X-Coordinate:
Initial Y-Top Starting Zone Coordinate: 395
Initial Y-Base Starting Zone Coordinate: 360

Cell Data

Cell No.	S.R.	Tang. C.	Norm. C.	Begin X	Begin Y	End X	End Y
1	0.4	0.83	0.3	0	397	5	395
2	0.4	0.83	0.3	5	395	16	390
3	0.4	0.83	0.3	16	390	24	385
4	0.4	0.83	0.3	24	385	32	380
5	0.4	0.83	0.3	32	380	40	375
6	0.4	0.83	0.3	40	375	50	370
7	1	0.83	0.3	50	370	56	365
8	1	0.8	0.3	56	365	60	360
9	2	0.8	0.3	60	360	67	355
10	0	0.9	0.4	67	355	72	338
11	0	0.9	0.4	72	338	77	338
12	0	0.9	0.4	77	341	78	341
13	0	0.9	0.4	78	338	82	323
14	0	0.92	0.42	82	323	105	323
15	0	0.92	0.42	105	323	121	320
16	1	0.81	0.3	121	320	127	315
17	1	0.81	0.3	127	315	132	310
18	1	0.81	0.3	132	310	138	305
19	1	0.81	0.3	138	305	146	300

CRSP Simulation Specifications: Used with c:\documents and settings\all users\desktop\Tim\CRSP Design 2 Fence.dat
Total Number of Rocks Simulated: 500
Starting Velocity in X-Direction: 0.3 m/sec
Starting Velocity in Y-Direction: -0.3 m/sec
Starting Cell Number: 1
Ending Cell Number: 19
Rock Density: 2646 kg/m^3
Rock Shape: Spherical
Diameter: 1 m

CRSP Analysis Point 1 Data - c:\documents and settings\all users\desktop\Tim\CRSP Design 2 Fence.dat
Analysis Point 1: X = 68, Y = 352
Total Rocks Passing Analysis Point: 28

Cumulative Probability	Velocity (m/sec)	Energy (J)	Bounce Ht. (m)
50%	7.83	51267	1.84
75%	8.99	65409	4.89
90%	10.04	78129	7.64
95%	10.67	85765	9.29
98%	11.37	94336	11.14

Velocity (m/sec)	Bounce Height (m)	Kinetic Energy (J)
Maximum: 11.09	Maximum: 3.99	Maximum: 98156
Average: 7.83	Average: 2.46	Average: 51267
Minimum: 4.76	G. Mean: 1.84	Std. Dev.: 20944
Std. Dev.: 1.72	Std. Dev.: 4.53	

CRSP Data Collected at End of Each Cell - c:\documents and settings\all users\desktop\Tim\CRSP Design 2 Fence.dat
Velocity Units: m/sec Bounce Height Units: m

Cell #	Max. Vel.	Avg. Vel.	S.D. Vel.	Max. Bounce Ht.	Avg. Bounce Ht.
1	No rocks		past end of cell		
2	No rocks		past end of cell		
3	3	3	0	0	-1
4	2	1	0	0	0
5	3	2	0	0	0
6	2	1	0	0	0
7	6	3	1.46	1	0
8	10	5	2.04	2	0
9	10	6	2.02	1	0
10	20	14	3.7	14	6
11	18	9	5.97	5	0
12	18	18	0	0	0
13	23	23	0	8	8
14	No rocks		past end of cell		
15	No rocks		past end of cell		
16	No rocks		past end of cell		
17	No rocks		past end of cell		
18	No rocks		past end of cell		
19	No rocks		past end of cell		

CRSP Rocks Stopped Data - c:\documents and settings\all users\desktop\Tim\CRSP Design 2 Fence.dat

X Interval	Rocks Stopped
0 To 10 m	72
10 To 20 m	34
20 To 30 m	87
30 To 40 m	90
40 To 50 m	74
50 To 60 m	83
60 To 70 m	32
70 To 80 m	27
80 To 90 m	1
90 To 100 m	0
100 To 110 m	0
110 To 120 m	0
120 To 130 m	0
130 To 140 m	0
140 To 146 m	0

Appendix 5

Point Load Testing Data

APPENDIX 5-1: RESULTS OF BLOCK POINT LOAD TESTING

Date 1-Jul-2008
Sample Location Eureka Bend

Note: All tests were block tests - calculate De as for axial test
Values shown in red are rejected results. Values with ~~strikethrough~~ are invalid.

Sample ID	Sample	Description of Failure	P (kN)	D (mm)	W (mm)	A = WD(mm²)	D_e^2	D_e	I_s	F	$I_{s(50)}$ (MPa)
1	Arthur Marble	Failed along weathered defect	4.12	34	49	1666	2121	46.05667	1.94	0.964	1.87
2	Arthur Marble		10.12	43.0	41	1763	2245	47.37849	4.51	0.976	4.40
3	Arthur Marble		10.47	44.0	59	2596	3305	57.492	3.17	1.065	3.37
4	Arthur Marble	Failed along weathered defect	5.42	48.0	56	2688	3422	58.50186	1.58	1.073	1.70
5	Arthur Marble		11.73	48.0	58	2784	3545	59.53737	3.31	1.082	3.58
6	Arthur Marble		15.50	48.0	54	2592	3300	57.44769	4.70	1.064	5.00
7	Arthur Marble		10.53	49.0	55	2695	3431	58.57799	3.07	1.074	3.30
~~8~~	~~Arthur Marble~~	Invalid	~~7.17~~	~~46.0~~	~~53~~	~~2438~~	~~3104~~	~~55.71407~~	~~2.31~~	~~1.050~~	~~2.43~~
9	Arthur Marble	Failed along weathered defect	1.82	48.0	59	2832	3606	60.04843	0.50	1.086	0.55
10	Arthur Marble		13.85	50.0	60	3000	3820	61.80387	3.63	1.100	3.99
~~11~~	~~Arthur Marble~~	Invalid	~~4.77~~	~~47.0~~	~~50~~	~~2350~~	~~2992~~	~~54.70021~~	~~1.59~~	~~1.041~~	~~1.66~~
12	Arthur Marble		8.10	47.0	60	2820	3591	59.92108	2.26	1.085	2.45
~~13~~	~~Arthur Marble~~	Invalid	~~8.77~~	~~50.0~~	~~54~~	~~2700~~	~~3438~~	~~58.6323~~	~~2.55~~	~~1.074~~	~~2.74~~
14	Arthur Marble		10.91	49.0	57	2793	3556	59.63353	3.07	1.083	3.32
15	Arthur Marble		9.83	42.0	53	2226	2834	53.2375	3.47	1.029	3.57
16	Arthur Marble		11.65	35.0	54	1890	2406	49.0553	4.84	0.991	4.80
17	Arthur Marble		17.16	46.0	60	2760	3514	59.28019	4.88	1.080	5.27
~~18~~	~~Arthur Marble~~	Invalid	~~8.69~~	~~49.0~~	~~57~~	~~2793~~	~~3556~~	~~59.63353~~	~~2.44~~	~~1.083~~	~~2.65~~
~~19~~	~~Arthur Marble~~	Invalid	~~7.88~~	~~44.0~~	~~78~~	~~3432~~	~~4370~~	~~66.10415~~	~~1.80~~	~~1.134~~	~~2.04~~
20	Arthur Marble		6.93	27.0	51	1377	1753	41.87184	3.95	0.923	3.65
21	Arthur Marble		7.98	24.0	51	1224	1558	39.47715	5.12	0.899	4.60
22	Arthur Marble		5.80	24.0	51	1224	1558	39.47715	3.72	0.899	3.35
23	Arthur Marble		12.12	26.0	49	1274	1622	40.27539	7.47	0.907	6.78
24	Arthur Marble	Failed along weathered defect	2.60	28.0	49	1372	1747	41.79575	1.49	0.923	1.37
25	Arthur Marble		10.51	27.0	51	1377	1753	41.87184	5.99	0.923	5.53
										Rejecting highest and lowest results, the mean Is(50)=	3.83
										Estimated uconfined compressive strength (σ_c) in Mpa =	92
1	Takaka Limestone - perp to bedding		4.97	41.0	53	2173	2767	52.5999	1.80	1.023	1.84
~~2~~	~~Takaka Limestone - perp to bedding~~	~~Invalid~~	~~2.56~~	~~39.0~~	~~54~~	~~2106~~	~~2681~~	~~51.78265~~	~~0.95~~	~~1.016~~	~~0.97~~
~~3~~	~~Takaka Limestone - perp to bedding~~	~~Invalid~~	~~6.04~~	~~43.0~~	~~56~~	~~2408~~	~~3066~~	~~55.37112~~	~~1.97~~	~~1.047~~	~~2.06~~
4	Takaka Limestone - perp to bedding	Platens were deeply embedded	7.84	44.0	59	2596	3305	57.492	2.37	1.065	2.53
5	Takaka Limestone - perp to bedding	Platens were deeply embedded	6.47	36	60	2160	2750	52.44232	2.35	1.022	2.40
6	Takaka Limestone - perp to bedding		7.92	38	63	2394	3048	55.20992	2.60	1.046	2.72
7	Takaka Limestone - perp to bedding	Weathered surface allowed platens to sink in initially	10.16	49	64	3136	3993	63.18923	2.54	1.111	2.83
8	Takaka Limestone - perp to bedding		9.30	46	67	3082	3924	62.64283	2.37	1.107	2.62
9	Takaka Limestone - perp to bedding		7.29	49	56	2744	3494	59.10812	2.09	1.078	2.25
10	Takaka Limestone - perp to bedding	Platens were deeply embedded in sample	5.72	49	56	2744	3494	59.10812	1.64	1.078	1.77
11	Takaka Limestone - perp to bedding		5.36	47	57	2679	3411	58.40384	1.57	1.072	1.69
12	Takaka Limestone - perp to bedding		5.64	39	42	1638	2086	45.668	2.70	0.960	2.60
										Rejecting highest and lowest results, the mean Is(50) =	2.34
										Estimated uconfined compressive strength (σc) in Mpa =	56
~~1~~	~~Takaka Limestone - parallel to bedding~~	Invalid	~~3.45~~	~~31~~	~~49~~	~~1519~~	~~1934~~	~~43.97785~~	~~1.78~~	~~0.944~~	~~1.68~~
2	Takaka Limestone - parallel to bedding		3.40	52	60	3120	3973	63.02783	0.86	1.110	0.95
3	Takaka Limestone - parallel to bedding		6.59	44	57	2508	3193	56.50916	2.06	1.057	2.18
4	Takaka Limestone - parallel to bedding		3.40	47	59	2773	3531	59.41964	0.96	1.081	1.04
5	Takaka Limestone - parallel to bedding		5.28	40	62	2480	3158	56.19283	1.67	1.054	1.76
6	Takaka Limestone - parallel to bedding		5.09	44	50	2200	2801	52.92567	1.82	1.026	1.86
7	Takaka Limestone - parallel to bedding		4.37	39	50	1950	2483	49.82787	1.76	0.998	1.76
~~8~~	~~Takaka Limestone - parallel to bedding~~	Invalid	~~3.94~~	~~47~~	~~59~~	~~2773~~	~~3531~~	~~59.41964~~	~~1.12~~	~~1.081~~	~~1.21~~
9	Takaka Limestone - parallel to bedding		4.14	48	60	2880	3667	60.55518	1.13	1.090	1.23
10	Takaka Limestone - parallel to bedding		3.01	37	49	1813	2308	48.04564	1.30	0.982	1.28
~~11~~	~~Takaka Limestone - parallel to bedding~~	Invalid	~~2.42~~	~~37~~	~~58~~	~~2146~~	~~2732~~	~~52.2721~~	~~0.89~~	~~1.020~~	~~0.90~~
12	Takaka Limestone - parallel to bedding		10.89	43	60	2580	3285	57.31455	3.32	1.063	3.53
~~13~~	~~Takaka Limestone - parallel to bedding~~	Invalid	~~3.43~~	~~41~~	~~53~~	~~2173~~	~~2767~~	~~52.5999~~	~~1.24~~	~~1.023~~	~~1.27~~
~~14~~	~~Takaka Limestone - parallel to bedding~~	Invalid	~~2.11~~	~~47~~	~~58~~	~~2726~~	~~3471~~	~~58.91393~~	~~0.61~~	~~1.077~~	~~0.65~~
15	Takaka Limestone - parallel to bedding		4.06	47	43	2021	2573	50.72689	1.58	1.007	1.59
										Rejecting highest and lowest results, the mean Is(50) =	1.71
										Estimated uconfined compressive strength (σc) in Mpa =	41

Appendix 6

Scanline Defect Data

Appendix 5-1: Data collected during scanline survey and key (from Wyllie and Mah, 2004).

Scanline Data for cut face at Eureka Bend

Chainage (m)	Dip	Dip Direction	Type	Spacing	Persistance	Surface Shape	Roughness	Wall Strength (Mpa)	Aperture	Infilling	# of sets	JRC	Seepage
0.00	68	045	Joint	5	1	3	2	R4	7	1	4	6	0
2.80	20	135	Bed	-	1	2	1	R4	4	1	1	9	0
4.30	30	200	Bed	5	0	3	2	R5	5	1	4	8	0
5.95	52	350	Joint	4	0	2	2	R4	5	1	2	8	0
6.60	66	010	Joint	4	1	2	2	R4	5	1	2	10	0
8.10	25	202	Joint	5	1	3	2	R5	4	1	4	7	0
8.20	60	338	Joint	6	0	2	1	R5	7	1	2	10	0
8.35	55	325	Joint	-	2	2	2	R5	5	1	1	6	0
8.40	54	022	Joint	5	0	3	1	R4	7	1	4	10	0
9.60	60	026	Joint	5	0	3	1	R4	8	1	4	10	0
11.20	76	045	Joint	5	1	2	1	R4	8	1	4	-	0
12.60	48	125	Joint	-	2	2	1	R4	1	1	1	12	0
14.00	22	162	Bed	5	1	3	1	R4	1	1	4	-	0
14.90	48	325	Joint	6	0	3	2	R4	4	1	2	7	0
18.40	25	188	Bed?	5	0	3	1	R3	4	1	4	-	0
19.80	48	325	Joint	-	0	2	1	R4	7	1	1	8	0
21.80	25	145	Bed	5	0	3	1	R3	4	1	4	10	4
21.60	62	320	Joint	-	0	3	1	R3	5	1	1	-	0
23.50	76	170	Joint	-	0	3	1	R5	8	1	1	-	0
24.70	55	025	Joint	-	1	3	1	R3	1	1	1	7	0
26.10	35	010	Joint	-	0	3	1	R4	4	1	1	6	0
27.20	65	205	Joint	-	0	2	2	R4	5	1	1	-	0
29.70	89	310	Joint	-	1	3	2	R4	7	1	1	10	0
31.30	74	150	Joint	-	2	3	1	R4	5	-	1	-	0

Type

0. Fault zone
1. Fault
2. Joint
3. Cleavage
4. Schistosity
5. Shear
6. Fissure
7. Tension Crack
8. Foliation
9. Bedding

Persistence

1. Very low persistence <1 m
2. Low persistence 1–3 m
3. Medium persistence 3–10 m
4. High persistence 10–20 m
5. Very high persistence >20 m

Aperture/width

1. Very tight (<0.1 mm)
2. Tight (0.1–0.25 mm)
3. Partly open (0.25–0.5 mm)
4. Open (0.5–2.5 mm)
5. Moderately wide (2.5–10 mm)
6. Wide (>10 mm)
7. Very wide (1–10 cm)
8. Extremely wide (10–100 cm)
9. Cavernous (>1 m)

Nature of filling

1. Clean
2. Surface staining
3. Non-cohesive
4. Inactive clay or clay matrix
5. Swelling clay or clay matrix
6. Cemented
7. Chlorite, talc or gypsum
8. Other — specify

Compressive strength of infilling

		MPa
S1	Very soft clay	<0.025
S2	Soft clay	0.025–0.05
S3	Firm clay	0.05–0.10
S4	Stiff clay	0.10–0.25
S5	Very stiff clay	0.25–0.50
S6	Hard clay	>0.50
R0	Extremely weak rock	0.25–1.0
R1	Very weak rock	1.0–5.0
R2	Weak rock	5.0–25
R3	Medium strong rock	25–50
R4	Strong rock	50–100
R5	Very strong rock	100–250
R6	Extremely strong rock	>250

Water flow (open)

0. Discontinuity is very tight and dry, water flow along it does not appear possible.
1. The discontinuity is dry with no evidence of water flow.
2. The discontinuity is dry but shows evidence of water flow, i.e. rust staining, etc.
3. The discontinuity is damp but no free water is present.
4. The discontinuity shows seepage, occasional drops of water, but no continuous flow.
5. The discontinuity shows a continuous flow of water (Estimate 1/mm and describe pressure, i.e. low medium, high).

Water flow (filled)

6. The filling materials are heavily consolidated and dry: significant flow appears unlikely due to very low permeability.
7. The filling materials are damp, but no free water is present.
8. The filling materials are wet; occasional drops of water.
9. The filling materials show signs of outwash, continuos flow of water (estimate litres/minute).
10. The filling materials are washed out locally; considerable water flow along out-wash channels (estimate litres/minute and describe pressure, i.e. low, medium, high).

Termination

0. Neither end visible
1. One end visible
2. Both ends visible

Surface shape

1. Stepped
2. Undulating
3. Planar

Surface roughness

1. Rough
2. Smooth
3. Polished
4. Slickensided

Spacing

1. Extremely close spacing <20 mm
2. Very close spacing 20–60 mm
3. Close spacing 60–200 mm
4. Moderate spacing 200–600 mm
5. Wide spacing 600–2000 mm
6. Very wide spacing 2000–6000 mm
7. Extremely wide spacing